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ALTERNATE MISSION STUDIES

(AILSS)

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July, 1969

Prepared under Contract No. NAS 1-7905 by
Hamilton Standard
Division of United Aircraft Corporation
Windsor Locks, Conn.

For National Aeronautics and Space Administration

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

This report has been prepared by the Hamilton Standard Division of United Aircraft Corporation for the National Aeronautics and Space Administration's Langley Research Center in accordance with Contract NAS 1-7905. The report covers work accomplished during Task 3 of the AILSS study that is not included in the AILSS final contract report. In particular, two pre-AILSS mission designs (with resupply) are defined, parametric weight curves of crew size and power supply are presented, and effects of mission parameters are examined.

Appreciation is expressed to the technical monitors, Mr. W. D. Hypes and Mr. F. W. Booth of NASA-Langley Research Center, for their advice and guidance during all phases of the AILSS study.

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ALTERNATE MISSION STUDIES

Hamilton Standard

A Division of United Aircraft Corporation

Windsor Locks, Connecticut

INTRODUCTION

The advent of longer duration space flights has necessitated the development of a new generation of environmental control and life support equipment and techniques. To satisfy future requirements, the evolution of such systems has been toward developing processes employing regenerative type life support equipment. The "Trade-off Study and Conceptual Design of Regenerative Advanced Integrated Life Support Systems (AILSS)" report describes various systems which meet this objective. The AILSS report is used to supplement the material presented here, particularly in regard to the candidate concept descriptions discussed within this report.

This report presents an evaluation of two additional environmental control and life support systems for an early AILSS type mission with resupply every 180 days. Two different electrical power supply systems are considered, and the optimum subsystem concepts for each power supply are chosen. One of the systems (Mission A) uses solar cell power which is extremely limited. The other system (Mission B) uses a Brayton cycle power supply where power is not a limitation. Flight dates for both systems are in the 1975-1977 period.

Included in this report are discussions of some of the major design considerations and constraints of space vehicles and their effect on equipment configuration, reliability, and weight. Items considered are the effect of resupply, artificial gravity, flight date, and crew size (50-100 men). Curves included show weight variation with time for the various candidate subsystem concepts and for three different power sources.

STUDY APPROACH

Objectives

The objectives of this study are:

1. Determine the optimum life support design for a power limited (solar cell) space station with a launch date of 1975-77.

2. Determine the optimum life support design for a space station launch in 1975-1977 with a Brayton cycle power supply.

Specifications and Guidelines

The study objectives are to be accomplished with certain guidelines and assumptions as agreed to with NASA Langley Research Center. These are identified in the following list. The conceptual designs for the solar cell and Brayton cycle systems are based on the specifications and requirements shown in table 1.

1. Projection of subsystem data is made for a 1975-1977 flight, although 1977 was selected as the go/no-go date for subsystem availability.

2. No specific vehicle configuration is considered.

3. Radiators are treated as "black boxes" because the configuration, sizing, and details of radiator construction do not affect the selection of EC/LS subsystem concepts.

4. Thermal power interfaces are not defined in detail.

5. Suit loop definition and consideration of EVA operations are not required.

6. Consideration of regeneration is given to all subsystem areas, with the exception of the food.

7. Overboard dump is limited to liquids and gases.

8. Consideration of integration of the EC/LS systems or subsystems with other vehicle systems, with the exception of power, is not required. Specifically, waste product utilization for the propulsion system, radiation shielding, etc., is not considered.

TABLE 1 - SPECIFICATIONS AND REQUIREMENTS

Mission		
Operational period		1975 to 1977
Mission duration		2-5 years life
Resupply capability		180 days
Gravity mode		0 to 1 g (in any direction)
Vacuum exposure		operation after exposure to hard vacuum for one week
Crew safety		probability of 0.99 for 500-day mission
Equipment MTBF		1000 hours, exclusive of instrumentation

Crew		
Crew size		nine men
Metabolic rate (24 hr-zero g average)		10 320 Btu/man day (150% basal metabolism rate)
Oxygen consumption		1.68 lb/man day
Carbon dioxide production		2.06 lb/man day
Metabolically formed water		0.78 lb/man day
Respiratory, perspiratory, excreted, and consumed water		affected by ambient temperature
Waste products		defined in Waste Control section
Crew metabolic activity		
Duty	8 hr	175% BMR
Sleep	8 hr	100%
Recreation	1 hr	500%
Eating and rest	6 hr	100%
Maintenance	1 hr	300%
24-hr average	- -	150% BMR

Atmosphere	
Cabin pressure	7.0 to 14.7 ±0.25 psia, constant for mission
Gas composition	3.5 ±0.1 psia oxygen, diluent nitrogen
Carbon dioxide partial pressure	
Normal	3.8 to 5.7 mm Hg
Normal maximum	7.6 mm Hg
Emergency maximum	15 mm Hg for 72 hr
Relative humidity	55 ±5%
Temperature	65 to 75° ±2°F selectable
Number of repressurizations	1 per resupply period (max.)
Contaminant list	presented in Contamination Control section

Spacecraft	
Vehicle free volume	10 000 cu ft
Vehicle leakage	one lb/day maximum
Wall heat leak	zero
Equipment heat load	
Communication	4000 watts
Instrumentation	1000
Control and guidance	1000
Scientific equipment	1500
Crew services	750
Coolant temperature available from radiator	36 to 40°F
Heat rejection penalty	0.04 lb/Btu/hr at 50°F to 0.015 lb/Btu/hr at 250°F
Compartmentation	two, with possibility of entire crew in either compartment
Extravehicular operation	undefined
Power heat sources and penalties	
Mission A - Power system: solar cell battery at 450 lb/kW	
Process heat source: electrical at 450 lb/kW	
Mission B - Power system: radioisotope powered Brayton cycle at 450 lb/kW	
Process heat source: power system waste heat at 375°F maximum at no penalty	

9. Manual handling of feces shall be precluded.

10. A whole body bath or shower shall be provided.

11. An onboard analysis instrumentation capability is required.

12. Cabin leakage is assumed to be zero for the purpose of designing the atmosphere contaminant control subsystem.

Selection Criteria

The selection of evaluation criteria is based on a recognition that some requirements are absolute, others are of primary importance, and still others are largely desirable rather than necessary. These criteria encompass both the total system performance requirements and the projected flight hardware operational characteristics. Performance requirements are covered primarily in the absolute criteria. Hardware factors are heavily stressed in the primary criteria: these are reliability, crew time (maintainability), and equivalent weight. Some integration aspects are considered in the primary criteria evaluations, but they are covered principally in the secondary criteria as shown in figure 1.

These criteria are applied sequentially in the groups shown to eliminate concepts that fail on either an absolute or comparative evaluation and to provide the basis for selection among surviving candidates.

The criteria used as a basis for the selection of subsystems are similar to those used in the AILSS study. The solar cell mission criteria are similar to those shown for the Brayton cycle with the exception that power, which is a major limitation of the solar cell system, is considered to be the primary criterion of first importance. Power is considered as a secondary factor in the Brayton cycle evaluation.

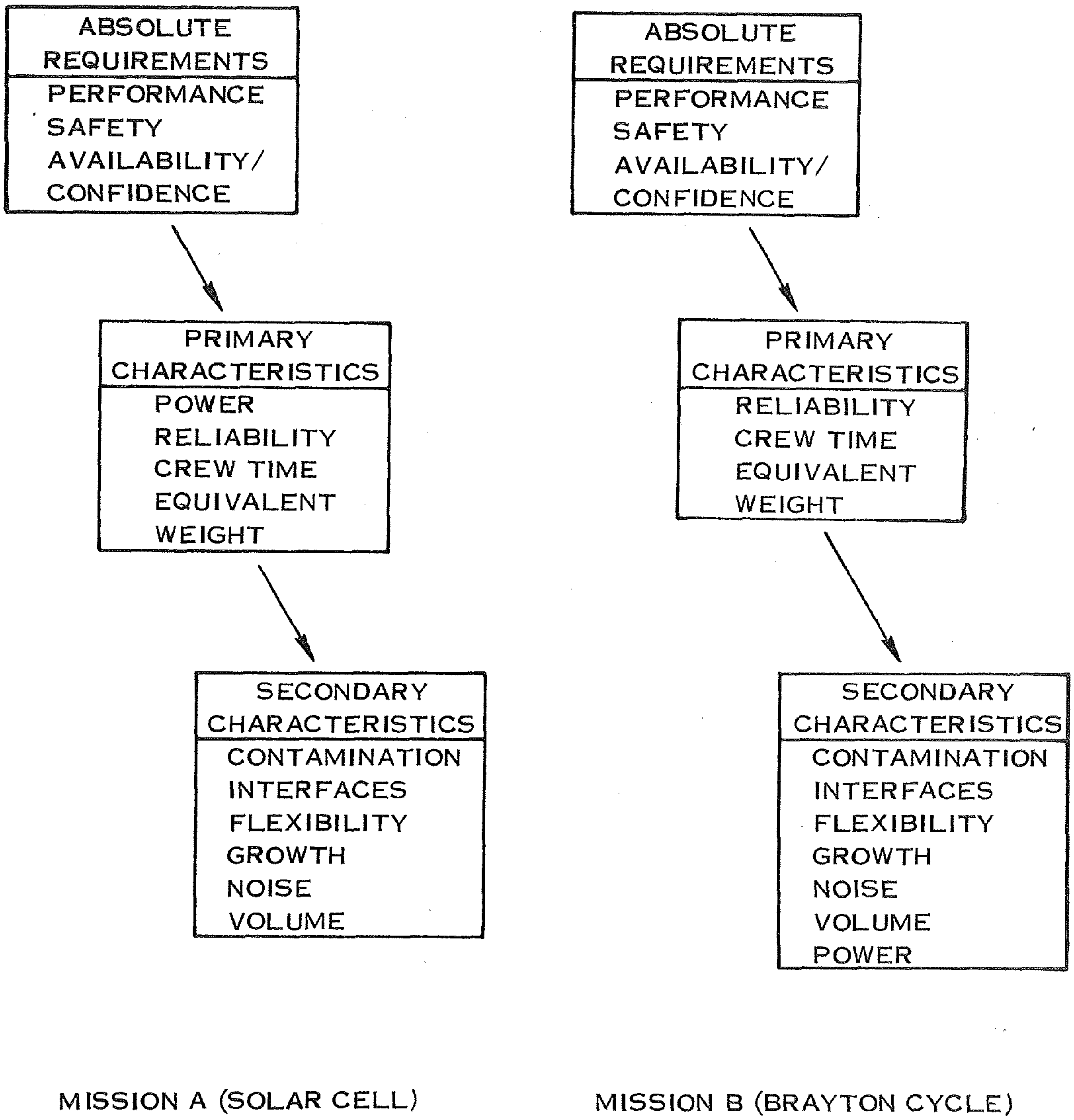

Figure 1. Selection Criteria.

MISSION A AND MISSION B SYSTEMS

Both pre-AILSS missions are earth-orbital and thus have resupply capability. Additional power supply constraints of Mission A (solar cell power supply), in conjunction with the availability and resupply capability considerations, have a significant impact on subsystem selections. In Mission B (Brayton cycle power and heat supply) availability is the major constraint. This system is therefore essentially similar to the AILSS Brayton cycle system, with the primary exception in the CO_2 reduction/ oxygen generation selections.

The availability constraint is an absolute criterion. Power limitations, however, require a trade of power (in watts) saved versus pounds of fixed and/or expendable weight. Here resupply was used to relieve the weight constraints, even though an increase in total pounds in orbit over the entire mission length would result. The real question of "How many pounds is a watt worth?" is based on a total vehicle cost effectiveness study, and is not treated in this report. For Mission A evaluations, power savings of less than a few hundred watts were not made if unreasonable weight increases resulted.

Resupply capability may be used for such obvious purposes as supply of large expendable food quantities, other expendables, and some spare parts. An attempt was made to avoid using periodic resupply as a reliability crutch, even though abort possibilites exist. The basic reliability and maintainability approach for the resupplied missions was the same as in the AILSS study report.

Schematics for the Mission A system and for the Mission B system are presented in figures 2 and 3, respectively. Table 2 presents a list of the Mission A subsystem selections and the power and weight numbers. Table 3 presents the same information for the Mission B system. Total equivalent weight are given for the first 180 day resupply period and for the total requirements of a two-year mission.

The total electrical power for each mission shows the solar cell system requiring 6730 watts and the Brayton cycle system 8050 watts. The primary importance of power in the evaluation of the solar cell subsystems accounts for the lower power for this system. This low power is obtained at the cost of higher fixed weight, resupply weight, and crew stress. The solar cell system total equivalent weight for 180 day launch is 13 047 pounds, approximately 670 pounds greater than the Brayton cycle system. The following table indicates the percentage of the total equivalent weight of each weight category for the two systems.

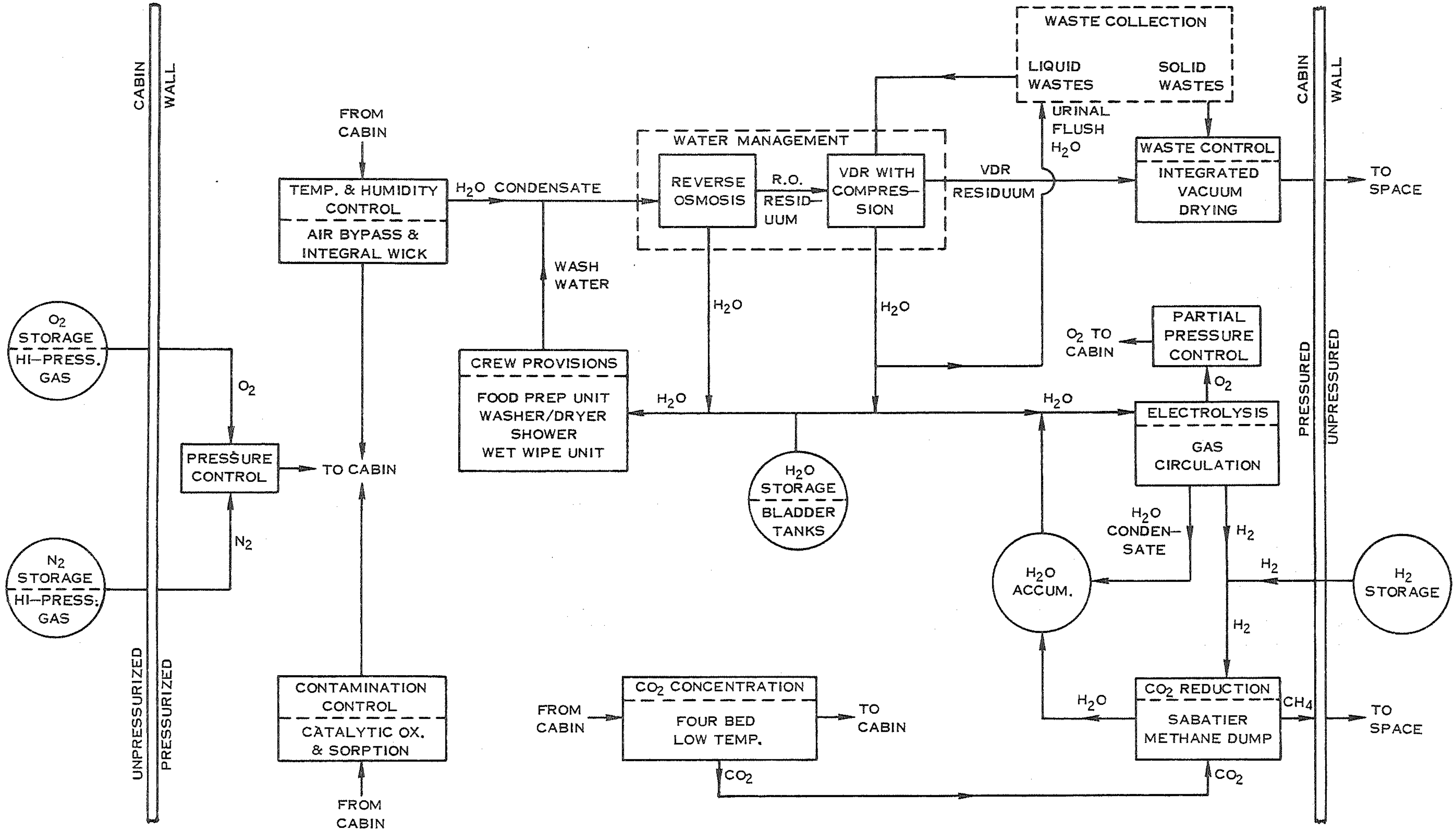

Figure 2. Mission A System Schematic.

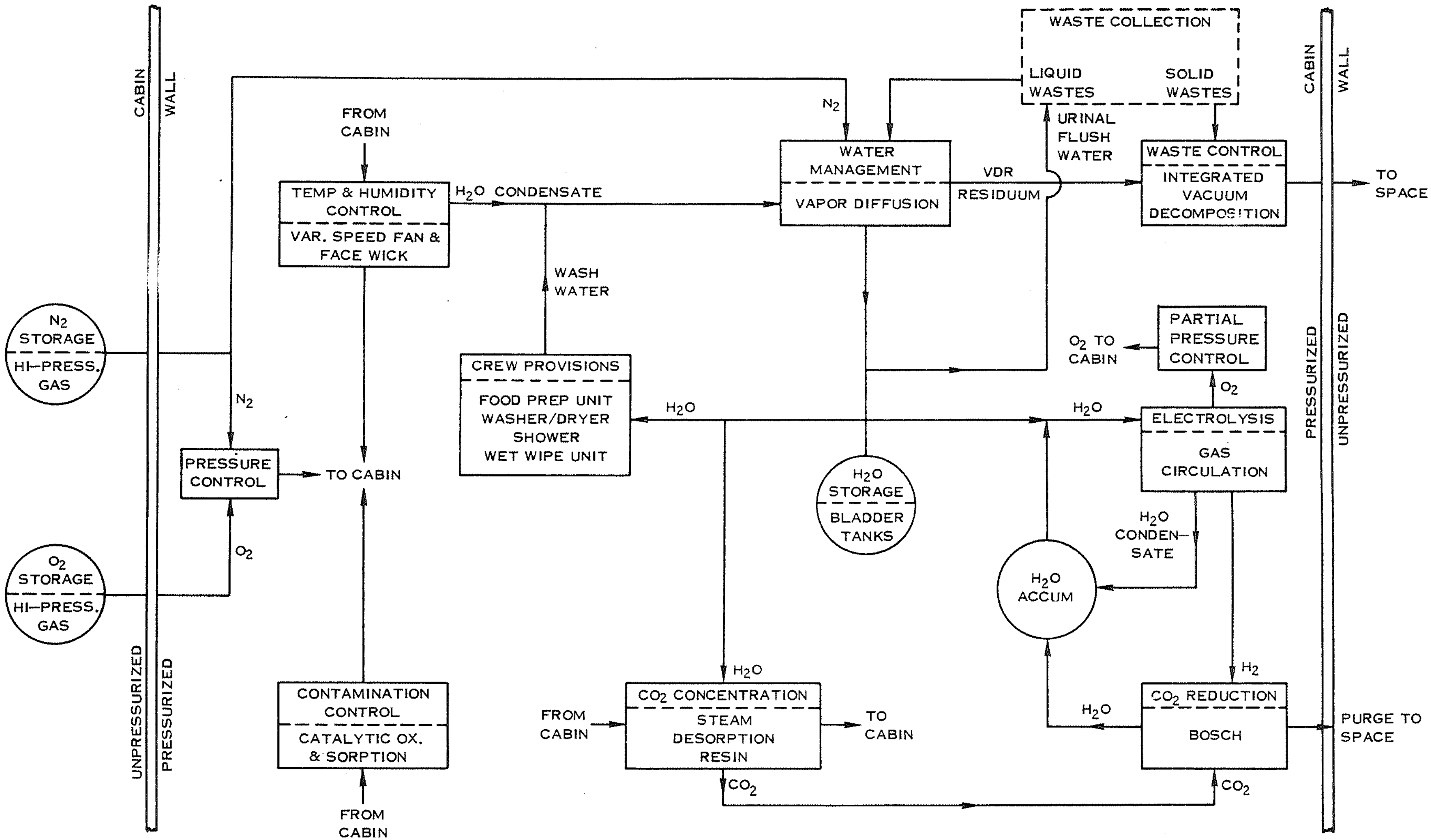

Figure 3. Mission B System Schem

TABLE 2. - SYSTEM SUMMARY - MISSION A

Function	Selected subsystem	Power watts	Power and heat rej. weight, pounds	Basic weight, pounds	180 day Expendable weight, pounds	Initial spares weight, pounds	Launch total equiv. wt., pounds	Two year total equiv. wt., pounds
Waste management	Integrated vacuum drying	191	86	82	600	150	918	2 718
Water reclamation	Wash H_2O + condensate - reverse osmosis	80	47	123	48	56		
	Urine + RO reject - VDR with compression	770	452	306	92	65	———	———
	Subsystem total	850	499	429	140	121	1 189	1 637
CO_2 concentrator	Molecular sieve	837	490	385	--	210	1 085	1 085
Water electrolysis	Gas circulation	1844	920	123	--	80	1 123	1 123
CO_2 reduction	Sabatier reactor - meth. dump	65	37	45	760	50	892	3 249
O_2 + N_2 storage	High press. filament wound tk.	--	--	938	302	9	1 249	2 155
Contaminant control	Catalytic oxidation/sorption	211	125	89	67	10	291	492
Temp. & humidity control	Air bypass - integral wick	1658	971	694	241	192	2 098	2 821
Thermal control	Water circulation loop	400	234	533	--	19	786	786
Crew provisions	Food, packaging + storage	--	--	828	2884	79	3 791	12 443
	Food preparation equip.	100	58	71	--	--	129	129
	Disposable clothing	--	--	--	650	--	650	2 600
	Miscellaneous supplies	--	--	--	72	--	72	288
Personnel hygiene	Shower	29	17	254	--	30	301	301
	Reusable body wipes	51	30	22	--	--	52	52
Instr. + controls	Data management	91	53	206	--	--	259	259
Resupplied spares	TBD prior to launch							124
System totals		6327	3520	4699	5716	950	14 885	32 262

TABLE 3. – SYSTEM SUMMARY MISSION B

Function	Selected subsystem	Power watts	Power and heat rej. weight, pounds	Basic weight, pounds	180 day Expendable weight, pounds	Initial spares weight, pounds	Launch total equiv. wt., pounds	Two year total equiv. wt., pounds
Waste Management	Integrated vacuum decomp.	1400	669	354	330	60	1 413	2 403
Water Reclamation	Vapor diffusion	67	618	369	117	55	1 159	1 510
O_2 concentration	Steam desorption - ion ex. res.	180	276	200	--	145	621	621
Water electrolysis	Gas circulation	1844	920	123	--	80	1 123	1 123
CO_2 reduction	Bosch	465	326	152	230	95	803	1 493
O_2 + N_2 storage	High press. filament wound tk.	--	--	938	302	9	1 249	2 155
Contaminant control	Catalytic oxidation/sorption	211	125	89	67	10	291	492
Temp. + humidity control	Variable speed fan/face wick	2017	1180	523	241	115	2 059	2 782
Thermal control	Water circulation loop	500	292	59	--	46	397	397
Crew provisions	Food, packaging + storage	--	--	828	2884	79	3 791	12 443
	Food preparation equip.	100	58	71	--	--	129	129
	Reusable clothing	320	186	139	--	14	339	339
	Miscellaneous supplies	--	--	--	72	--	72	288
Personal hygiene	Shower	29	17	254	--	30	301	301
	Reusable body wipes	51	30	22	--	--	52	52
Instr. + controls	Data management	91	53	206	--	--	259	259
Resupplied spares	TBD prior to launch							117
System totals		7275	4750	4327	4243	738	14 058	26 904

	Fixed Weight, %	180 Day Expendable Weight, %	Spares, %	Power, %
Mission A/Solar Cell	31.6	38.4	6.4	23.7
Mission B/Brayton Cycle	30.8	30.2	5.2	33.8

The 180-day resupply weight for the solar cell system is 1473 pounds heavier than the Brayton cycle. The difference is due primarily to hydrogen resupply for the Sabatier process and waste collector canisters for the vacuum drying system.

AILSS

If the same power limiting constraint were imposed on the AILSS (500 day no resupply) mission, the EC/LS design would be changed as follows:

1. Change integrated vacuum decomposition subsystem to a vacuum drying subsystem. Power saving is 1650 watts.

2. Process wash water and condensate with a reverse osmosis unit and process urine and urine flush water with a vapor diffusion/compression rather than use vapor diffusion/compression for all other functions. Power saving is 800 watts.

3. Use the low power integral wick heat exchanger design with an air bypass temperature control for temperature and humidity control. Power saving is 350 watts.

4. Use membrane CO_2 concentrator requiring no energy for heating purposes. This would give a further power decrease of 600 watts.

The above subsystem changes would result in an AILSS Design 1 EC/LS system power decrease from 10 339 watts to about 7000 watts. Additional minor changes might be made by reducing air cooling loads and making other system refinements. These changes of course would be made at the expense of increased weight, lower reliability, and higher crew time.

Mission A System

Some of the subsystems making up the Mission A system are the same as those selected for the AILSS and some are different. Where differences occur, the Mission A choices are selected because of availability or because they consume less electrical power. Resupply capability was also a factor in the Mission A subsystem selections.

Oxygen and nitrogen storage and the pressure and composition control concepts are the same as those selected for the AILSS. Thus, both oxygen and nitrogen are stored as high pressure (3000 psia) gases. The pressure control subsystem admits oxygen and nitrogen, in a fixed ratio, to the cabin whenever total cabin pressure is lower than the set point. Oxygen partial pressure is controlled by the oxygen generation subsystem.

The O_2 generation/CO_2 control system consists of a water electrolysis subsystem, a CO_2 concentration subsystem, and a CO_2 reduction subsystem. The electrolysis unit generates oxygen from water at the average metabolic rate. Rate of electrolysis is adjustable to keep cabin oxygen partial pressure within specified limits. Byproduct hydrogen generated by the electrolysis process is supplemented with stored hydrogen and delivered to the CO_2 reduction subsystem. There, the hydrogen is reacted with CO_2 removed from the cabin air by the CO_2 concentration subsystem. The products of this reaction are methane and water. The methane is dumped to space, while the water is removed and recycled to the water electrolysis subsystem. The gas circulation concept, a vapor-fed immobilized matrix design, is used for water electrolysis. Part of the recirculating oxygen is diverted to the cabin to supply metabolic needs. Feed water is added and transported as a vapor to the cells, where it is absorbed by the electrolyte and electrolyzed. The CO_2 concentration concept, with lower power consumption than the AILSS selection, is a molecular sieve unit. Inlet cabin air is predried by adsorption of water vapor on one of two cycling silica gel beds before entering one of two cycling molecular sieve beds, where CO_2 is removed by adsorption. Water is removed from the desorbing silica gel desiccant bed by heatless (rapid cycling at ambient temperature) desorption into the air returning to the cabin. CO_2 is removed from the desorbing molecular sieve bed into an accumulator by a combination of vacuum and low temperature (200°F) heat. The concentrated CO_2 in the accumulator is fed into the CO_2 reduction subsystem. The CO_2 reduction subsystem minimizes power by using the Sabatier-methane dump concept. The Sabatier reaction, which combines CO_2 and hydrogen to form methane and water, requires no heating power except for startup. Furthermore, because the methane is dumped overboard and the product water condensed, no gas recirculation compressor is needed. Carbon handling is also avoided.

Atmospheric contamination control is accomplished by a combination of catalytic oxidation, chemical absorption, and absolute filtration, just as it is in the AILSS.

Thermal control regulates cabin temperature and humidity by an air bypass arrangement using integral wick heat exchangers. This concept permits lower pressure drop and higher efficiency fans than the AILSS selection, resulting in significantly lower power consumption.

Water management is accomplished by adding a reverse osmosis unit to the vapor diffusion-compression concept selected for the AILSS solar cell design. Condensate and wash water are combined and are processed by the reverse osmosis unit. The resulting purified water is ready for storage and use by the crew, while the residuum is fed to the vapor diffusion-compression unit, together with pretreated urine and flush water. Here, water is purified by evaporation through a semipermeable membrane before being stored in heated, bladder storage tanks. The vapor diffusion-compression unit residuum is transferred to the waste control subsystem. The two major power-reducing features of the Mission A water management system are condensate and wash water preprocessing by the low power reverse osmosis unit and recovery of the heat of condensation with use of the compression in the vapor diffusion-compression unit.

Waste control is accomplished with the integrated vacuum drying concept, which requires far less power than the AILSS selection. Waste water residuum from the water management subsystem and fecal and other solid wastes are processed by exposure to space vacuum at cabin temperature. This removes much of the contained water, rendering the residual material bacteriostatic. This material is accumulated, stored, and removed during resupply.

In the crew provisions area, food and personal hygiene selections are similar to those of the AILSS, with use of freeze-dried food and a shower. Disposable clothing is selected, however, to effect a power reduction of 320 watts.

The instrumentation concept is somewhat less sophisticated than that of the AILSS in that fault isolation requires more crew member participation. A computerized data management system will be used, however, to the fullest extent possible at the flight dates.

Thus, the Mission A system minimizes electrical power consumption and takes advantage of resupply capability wherever possible.

Mission B System

Mission B is not power critical as is Mission A, and the EC/LS system is therefore closer to the AILSS than the Mission A system. In fact, the Mission B system concept is similar to the AILSS Design 3 (Brayton cycle design), except in the areas of water management and oxygen generation/CO_2 control. All other areas use the same concepts as the AILSS.

Thus, oxygen and nitrogen are stored as 3000 psia high pressure gases. Total cabin pressure is controlled by delivering these gases in a fixed ratio, while oxygen partial pressure is controlled by regulating oxygen generation rate of the O_2 generation/CO_2 control subsystem. Atmospheric contamination control is accomplished by a combination of catalytic oxidation, chemical absorption, and absolute filtration. Thermal control is achieved with variable speed fans coupled to face-wicked heat exchangers. Waste is eliminated by an integrated vacuum decomposition process. Crew provisions include a freeze-dried diet, a shower, and reusable clothing. The computerized data management approach is used in the instrumentation subsystem.

Water management is also similar, in part, with the Design 3 AILSS in that waste waters are processed in a vapor diffusion unit. Because bladderless tanks will not be fully developed, however, the purified water is stored in bladder tanks.

Like the Mission A system and unlike the AILSS, the O_2 generation/CO_2 control subsystem includes a separate water electrolysis unit, as well as CO_2 concentration and reduction units. The Mission B subsystem, however, is different from either of the others. As in the Mission A system, oxygen is generated by a gas circulation water electrolysis process and byproduct hydrogen is reacted with concentrated CO_2 in the CO_2 reduction unit. The products of this reaction, however, are carbon (rather than methane) and water. The solid carbon is removed (with the used catalyst cartridge) and stored until picked by the resupply vehicle. The water is condensed and recycled to the water electrolysis unit. A purge of the Bosch reactor to space eliminates the nitrogen impurity in the concentrated CO_2. Like the AILSS, the Mission B system uses a steam desorbed resin CO_2 concentrator. The CO_2 reduction unit uses the Bosch process to react CO_2 with hydrogen, forming solid carbon and water. Hydrogen is not discarded from this system and therefore need not be resupplied.

Limited by availability, the instrumentation subsystem is similar to that of Mission A. It uses the computer for data management, but fault isolation requires considerable participation by the crew.

Thus, the Mission B system is very much like the Design 3 AILSS, except where it is limited by hardware availability.

SUBSYSTEM SELECTIONS FOR MISSIONS A AND B

Selection of subsystems for Missions A and B is based on the evaluation criteria described earlier. Many of the selections are the same as for the AILSS, but some are significantly different. For Mission A, differences occur mainly because of the earlier flight date and the criticality of electrical power. For Mission B, differences result from the earlier flight date.

Selections are made for the following subsystems:

- Oxygen and nitrogen storage
- Pressure and composition control
- Water electrolysis
- CO_2 removal and concentration
- CO_2 reduction
- Atmosphere contamination control
- Temperature and humidity control
- Water management
- Waste control
- Crew provisions
- Instrumentation

Oxygen and Nitrogen Storage

Metabolic oxygen requirements are provided by the reduction of man-produced carbon dioxide and water in the oxygen generation subsystem. The existence of vehicle gas leakage and cabin repressurization requirements necessitates the onboard storage of the primary cabin atmospheric constituents, oxygen and nitrogen.

<u>Mission A and Mission B selections.</u> - Power, which is the only differentiating criterion between Mission A and B selections, is not a significant factor in the atmospheric storage selection. The selected high pressure storage method is therefore applied to both missions. Those methods considered are:

1. High pressure storage
2. High pressure storage with electrolysis for O_2 leakage
3. Subcritical storage
4. Supercritical storage

All of these systems can be developed in the required time.

At the present time there is no means of refilling cryogenic tanks in orbit. Replacing cryogenic tanks means that small tanks will have to be used so that they can be handled in zero gravity. A large number of fluid connections (4-6 per tank) will have to be made whenever the tanks are replaced. Resupply of cryogenically stored O_2 and N_2 is therefore undesirable. Based on the fact that tanks must be replaced in orbit, high pressure, filament wound tanks are chosen for O_2 and N_2 storage. Filament wound pressure vessels are rapidly being accepted for man-rated applications, and the acceptable stress levels are constantly increasing. Therefore, as weight is considered competitive, the much higher reliability and lower crew times result in the selection of high pressure storage in filament wound tanks.

Combined high pressure storage and electrolysis of stored water for O_2 leakage makeup appears desirable for large leakage rates. For the low leakage rates assumed for Missions A and B, the small savings in weight, however, do not justify the lack of operating flexibility of separate storage. If the cabin leakage were larger, hydrogen generated by water electrolyzed for leakage oxygen could substantially reduce hydrogen storage requirements.

Pressure and Composition Control

With no availability problem or significant power consumption, the AILSS concept is also selected for both Mission A and Mission B. Thus, oxygen and nitrogen are delivered in a fixed ratio for cabin leakage make-up, and acceptable oxygen partial pressure is maintained by modulating the oxygen generation subsystem output.

Water Electrolysis

Water electrolysis units are required in both missions under consideration to generate metabolic oxygen requirements. An oxygen rate of 15.1 pounds per day must be generated from 17.0 pounds of water. This water is made up partially from CO_2 reduction and partially from metabolically generated water. Hydrogen produced by electrolysis of this water is transported to the CO_2 reduction unit for consumption in the hydrogeneration process.

Mission A and Mission B selections. - Table 4 shows the electrolysis concepts considered to be available by 1977. The evaluation made of these candidates was considered applicable for both Missions A and B. Electrical power penalty, which is the only differentiating criterion between the two missions, is the same for both missions. This is because there is no heating requirement for any of the electrolysis systems which would allow a reduction in electrical penalty for the Brayton cycle system.

TABLE 4 - EVALUATION SUMMARY - WATER ELECTROLYSIS - MISSIONS A AND B

	CRITERIA	Cabin Air	Gas Circulation	Wick Feed	Ion Exchange Resin	Ion Exchange Membrane	Circulating Electrolyte	Rotating
Absolute	Performance	Good	Good	Good	Good	Good	Good	Good
	Safety	Fair	Very Good	Very Good	Very Good	Fair	Fair	Fair
	Avail./Conf.	Good	Good	Good	Fair	Fair	Fair	Fair
Primary	Power	Fair	Very Good	Very Good	Poor	Fair	Good	Fair
	Reliability	Poor	Fair	Fair	Fair	Fair	Fair	Fair
	Crew Time	Very Good	Good	Fair	Fair	Fair	Good	Fair
	Equivalent Weight	Fair	Very Good	Very Good	Poor	Good	Good	Good
		Eliminated		Eliminated	Eliminated	Eliminated	Eliminated	Eliminated
Secondary	Contamination		Very Good					
	Interfaces		Fair					
	Flexibility		Good					
	Growth		Good					
	Noise		Good					
	Volume		Very Good					
			Selected					

Based on low power requirements, the outstanding systems are wick feed and gas circulation. Wick feed is further advanced than the gas circulation concept, but both can be available by 1977. The wick feed concept requires a zero gravity gas separator to prevent dissolved gas in the feed water from becoming trapped in the cell modules. There is no significant difference in weight or power between the two systems. Both systems integrate well with the CO2 reduction system.

The gas circulation concept, shown in figure 4, is a vapor feed system. In normal operation, water from the water management subsystem is fed to the evaporator by a metering pump. Gas is circulated by a fan through the cell modules, and over an evaporator, picking up water, and returns to the cell module inlet. Within the cells, water vapor is absorbed from the circulating oxygen stream into an electrolyte matrix. Hydrogen and oxygen generated at the cell leave through a dual-passage condenser-separator. Condensate is pumped back to the evaporator. Heat is removed by coolant tubes passing through the cell modules, thereby providing positive temperature control of the process. The oxygen generation rate is controlled by the simultaneous variation of electrolysis current and water feed pump speed.

CO_2 Removal and Concentration

The crew exhales carbon dioxide at a rate of 18.5 pounds per day. This carbon dioxide must be removed from the atmosphere to an acceptable level, and transported to a reduction system for reclamation of contained oxygen.

The CO_2 concentrator subsystem must perform the control function by maintaining CO_2 partial pressure at a maximum of 7.6 mm Hg. Normal concentrations will be between 3.8 and 5.7 mm Hg, depending on crew activity. During emergencies, CO_2 partial pressure must not exceed 15 mm Hg for a maximum period of 72 hours.

Collected CO_2 is compressed to 40 psia and delivered to the reduction system (either Sabatier or Bosch) at a purity of 98 percent. The two percent impurity is composed of oxygen and nitrogen transferred along with the CO_2. Oxygen is consumed in the reaction and the nitrogen is either dumped overboard (in the Sabatier) or purged from the reactor (in the Bosch).

Mission A-CO_2 concentration selection. - Of the CO_2 concentrator concepts initially considered in the AILSS study, only those expected to be available in 1977 were retained for further evaluation. Their relative ratings are shown in table 5.

Electrodialysis and the solid amine concept require more than twice the power of the molecular sieve system, so they were eliminated from consideration. The difference in total equivalent weight between steam desorbed resin and molecular sieve low temperature desorption is calculated to be 20 pounds for 180 days, which is

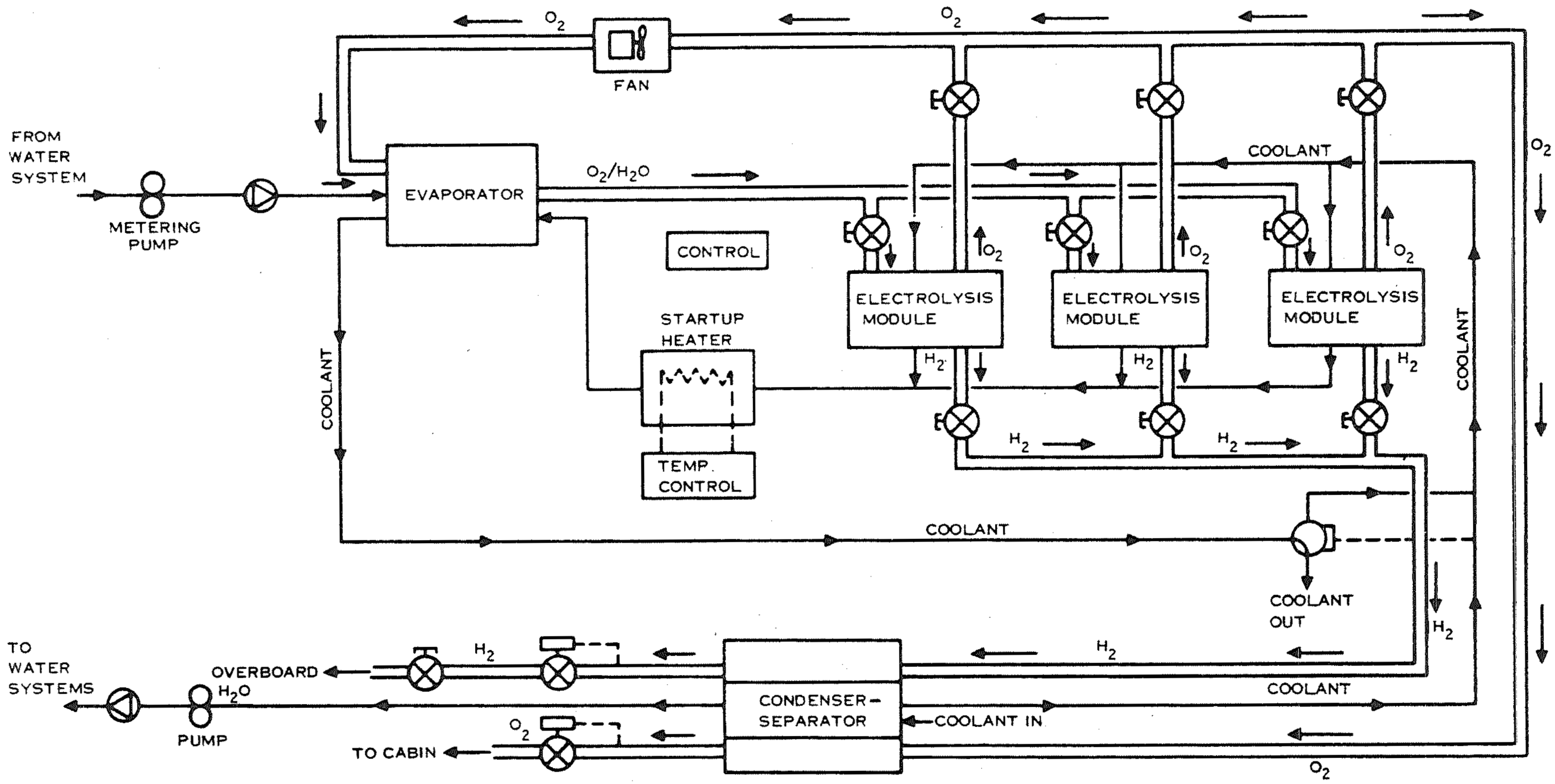

Figure 4. Gas Circulation Electrolysis Concept.

TABLE 5
EVALUATION SUMMARY - CO_2 CONCENTRATION - MISSION A

	CRITERIA	Molecular Sieve	Solid Amine	Steam Desorbed Resin	Electrodialysis Cell	Membrane Diffusion
Absolute	Performance	Good	Good	Good	Very good	Very good
	Safety	Very good	Good	Very good	Good	Good
	Avail./Conf.	Very good	Good	Good	Good	Unacceptable
						Eliminated
Primary	Power	Fair	Poor	Fair	Poor	
	Reliability	Good	Good	Very good	Fair	
	Crew Time	Very good	Very good	Good	Poor	
	Equivalent Weight	Good	Fair	Very good	Fair	
		Selected	Eliminated	Eliminated	Eliminated	

negligible. The molecular sieve low temperature system has a higher rating in availability/confidence then the steam desorbed resin system but is less reliable. The steam desorbed resin requires 170 watts more than the molecular sieve system. Based on its lower power, the molecular sieve system is chosen.

Membrane diffusion requires only half the power of the molecular sieve concept. However, this system was not considered because it will not be ready by 1977. A major breakthrough in membrane technology, however, could result in its availability by the scheduled flight date.

The molecular sieve concept is shown schematically in figure 5. Basic to the operation of a molecular sieve system is a sorbent material that has a high affinity for CO_2, usually an artificial zeolite. Two canisters function alternately in adsorbing and desorbing modes. Because the sorbent has a preferential affinity for water vapor, an additional pair of desiccant canisters, usually containing silica gel, is used to adsorb the moisture from the process stream before it enters the CO_2 removal beds. The desiccant beds are regenerated by passing the effluent air from the molecular sieve canister through the desorbing desiccant canister, where the contained water rehumidifies the air. The molecular sieves are desorbed in a sequenced operation. Atmospheric gas filling the void volume in the isolated, desorbing zeolite canister is returned to the concentrator inlet by the compressor. The accompanying reduction in canister pressure to 0.1 psia causes partial desorption of air and carbon dioxide, which return with the void volume gas. This ullage and adsorbed air removal is necessary for delivery of high purity CO_2.

In the second phase of this recovery operation, the compressor discharge is diverted into the accumulator by a solenoid-operated valve. The compressor maintains reduced pressure in the desorbing zeolite canister and transfers the carbon dioxide to the accumulator as it is desorbed. This desorption process is accelerated by the transfer of heat at 200° F to the zeolite bed from the heating fluid, which circulates through coils in the bed. Near the end of the cycle, cold fluid replaces the hot fluid to precool the bed prior to adsorption.

Mission B-CO_2 concentration selection. - With power as a secondary criterion, an evaluation of table 6 has resulted in the selection of a steam desorbed resin concept as the CO_2 concentrator subsystem for Mission B. This selection is based mainly on the primary design criteria of outstanding reliability and total equivalent weight, with reasonable crew time and support from absolute and secondary criteria.

If unexpected development problems arise or if peak power requirements are unacceptable, the molecular sieve concept, with somewhat higher complexity and equivalent weight, is an attractive alternative.

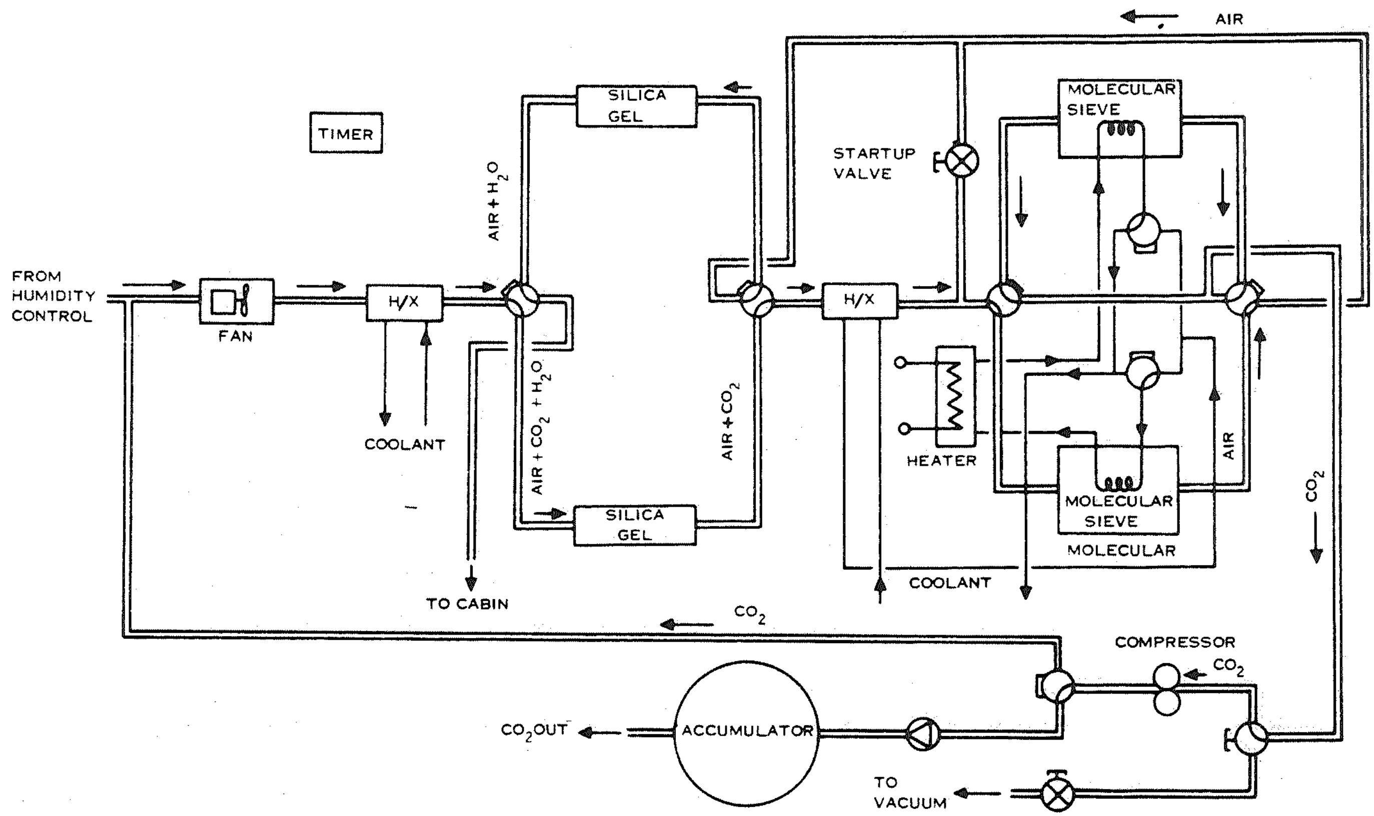

Figure 5. Molecular Sieve CO_2 Concentrator Concept.

TABLE 6 - EVALUATION SUMMARY - CO_2 CONCENTRATION - MISSION B

CRITERIA		Molecular Sieve	Solid Amine	Steam Desorbed Resin	Electrodialysis Cell	Membrane Diffusion
Absolute	Performance	Good	Good	Good	Very good	Very good
	Safety	Very good	Good	Very good	Good	Good
	Avail./Conf.	Very good	Good	Good	Good	Unacceptable
						Eliminated
Primary	Power	Fair	Fair	Good	Poor	
	Reliability	Good	Good	Very good	Fair	
	Crew time	Very good	Very good	Good	Poor	
	Equivalent Weight	Good	Good	Very good	Fair	
		Eliminated	Eliminated	Selected	Eliminated	

The steam desorption system is shown schematically in figure 6. The two sorbent beds operate cyclically. In normal operation, both beds may be absorbing, or one may be absorbing and the other desorbing, at any given time. Each bed desorbs only 25 percent of the time. When both beds are absorbing CO_2, cabin air is directed through both beds, in parallel, by a single fan. The ion exchange resin in each bed absorbs CO_2 on a timed cycle until effluent CO_2 concentration is 40 to 50 percent of influent concentration. When one bed reaches this condition, it begins the desorption phase (while the other bed continues absorption), influent air bypassing this bed.

During desorption, steam at ambient pressure is generated and directed into the desorbing resin bed. For the first part of this phase, steam condensing on the sorbent displaces absorbed CO_2 farther and farther along the bed because of the bed's greater affinity for H_2O. At the same time, void volume air is displaced through a valve to the cabin. In the second part of the desorption phase, this valve diverts to the concentration position, and nearly pure saturated CO_2 is delivered to the accumulator by a compressor. At the end of the desorption phase, bed temperature is 180 to 200° F and a significant quantity of condensed steam is dispersed throughout the solid resin. When the adsorption phase starts, this condensed steam evaporates into the influent cabin air, cooling the bed and making room for more CO_2. A condenser-separator removes this water vapor from the effluent air. Another condenser-separator removes excess water vapor from the CO_2 before it enters the accumulator.

CO_2 Reduction

In general, the requirements of the CO_2 reduction unit are to process 18.5 pounds of CO_2 and produce 15.1 pounds of water for electrolysis. With an additional 1.9 pounds of water from the water management system, 15.1 pounds of oxygen are ultimately produced for metabolic consumption.

The CO_2 reduction system must therefore be used in conjunction with a CO_2 concentrator and a water electrolysis unit. However, CO_2 reduction can be considered independently here, because all reduction subsystems available for Missions A and B must be integrated with a separate water electrolysis unit and a CO_2 concentration unit to form an integrated O_2 generation/CO_2 control subsystem. This is not true for the AILSS, where the trade-off must be made on the integrated subsystem level because of the additional oxygen generation concepts available in the 1976-1980 time period.

Mission A-CO_2 reduction selection. - There are only two systems that can be available in the 1975-77 time period. These systems are Bosch and Sabatier with methane dump. Other concepts initially considered but rejected due to availability are fused salt, solid electrolyte, and Sabatier with methane cracking. Table 7 presents a relative comparison of the Bosch and Sabatier-methane dump concepts for the established criteria. The table below gives a quantitative breakdown of the values for power and weight of these systems.

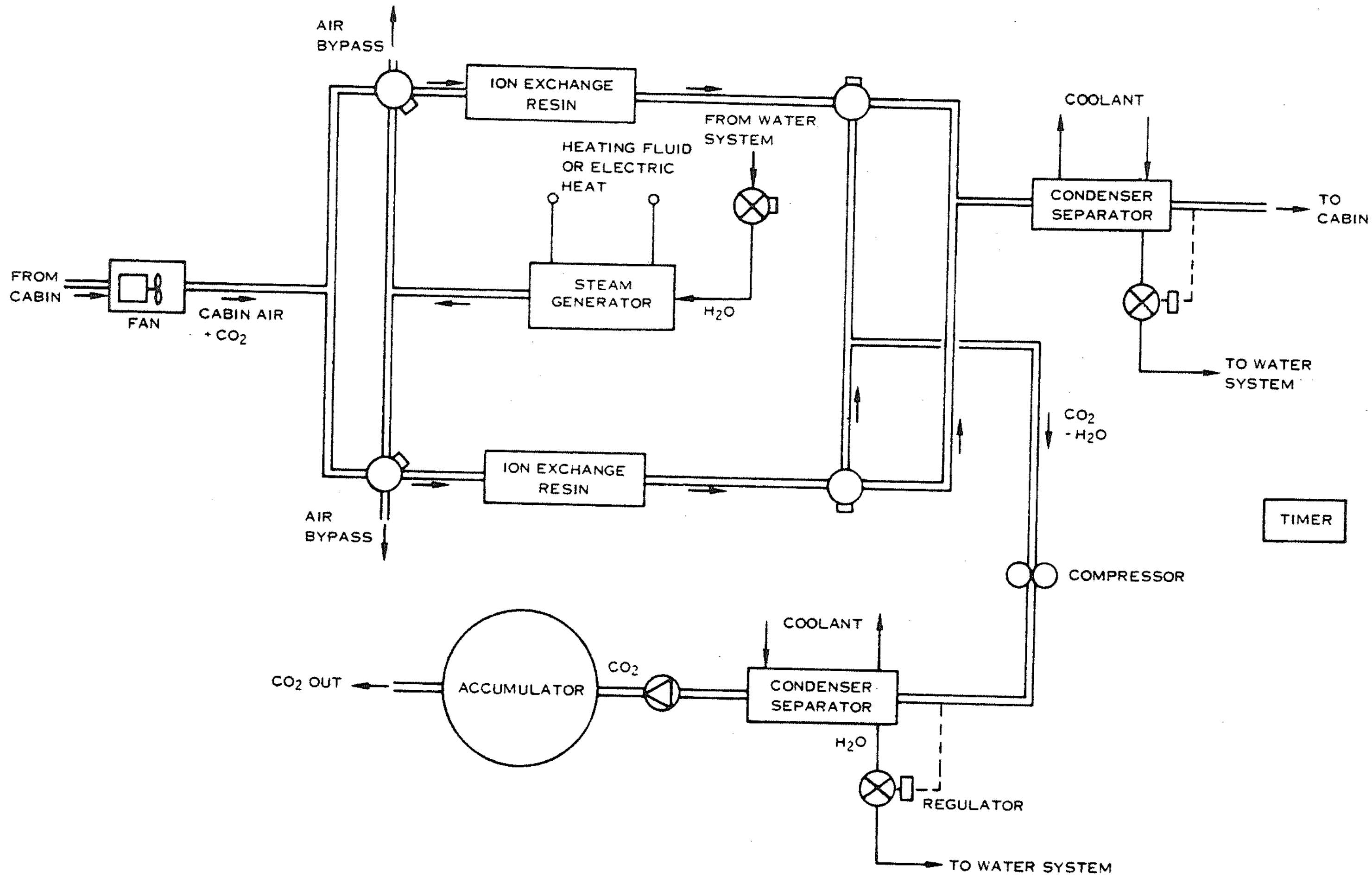

Figure 6. Steam Desorbed Resin CO_2 Concentrator Concept.

TABLE 7 - EVALUATION SUMMARY - CO_2 REDUCTION - MISSION A

CRITERIA		Bosch	Sabatier - Methane Dump
Absolute	Performance	Good	Good
	Safety	Fair	Fair
	Avail./Conf.	Good	Very good
Primary	Power	Fair	Good
	Reliability	Fair	Fair
	Crew time	Good	Very good
	Equivalent Weight	Very good	Poor
		Eliminated	Selected

Candidate	Power (watts)	Basic wt. (lb)	180 Days Spares (lb)	180 Days Expendables (lb)
Bosch	465	152	95	230
Sabatier-methane dump	65	45	50	760

The Bosch is much the lighter system since it requires no hydrogen storage, but it requires 400 watts more than the Sabatier system. The main weight difference between the systems is due primarily to the hydrogen resupply for the Sabatier-methane dump. The hydrogen tanks have been considered to be expendables. The Sabatier-methane dump concept is considered available now since several flight prototype units have been built and successfully tested. Since carbon is disposed of as a gas in the Sabatier process, and no carbon collection device is required, estimated crew time is much lower than for the Bosch concept.

Based on the lower power requirements and favorable ratings for other absolute and primary criteria, and capability for resupply, the Sabatier-methane dump concept is selected for Mission A.

This system is shown schematically in figure 7. The Sabatier-methane dump system uses a single reduction reactor operating at about 600° F. It is a hydrogenation process. In addition to the reactors, the reduction section includes a regenerative heat exchanger, a condenser-separator, a condensate pump (which can be eliminated during subsystem integration), a hydrogen supply tank, and control devices. This system does not generate carbon, but dumps it overboard as methane (CH_4). In addition to the reduction section, the system requires CO_2 concentration and water electrolysis sections.

During normal operation of the reduction section, carbon dioxide (from the concentrator and hydrogen (from electrolysis and/or storage) are combined and fed to the hydrogenation reactor. There the carbon dioxide is hydrogenated to form water vapor and methane. Water vapor in the reactor effluent is condensed, separated from the methane, and transferred to the water management system. The methane is then dumped to space together with the excess hydrogen.

Mission B-CO_2 reduction selection. - The Bosch system has been selected for Mission B, based on its availability and low weight. A full scale unit of the Bosch system has been run as an integrated system, although carbon handling was a problem. Current carbon collection work has proven promising. This system is a closed loop concept and is not subject to the CO_2 losses encountered by the Sabatier-methane dump concept. Table 8 summarizes the evaluation.

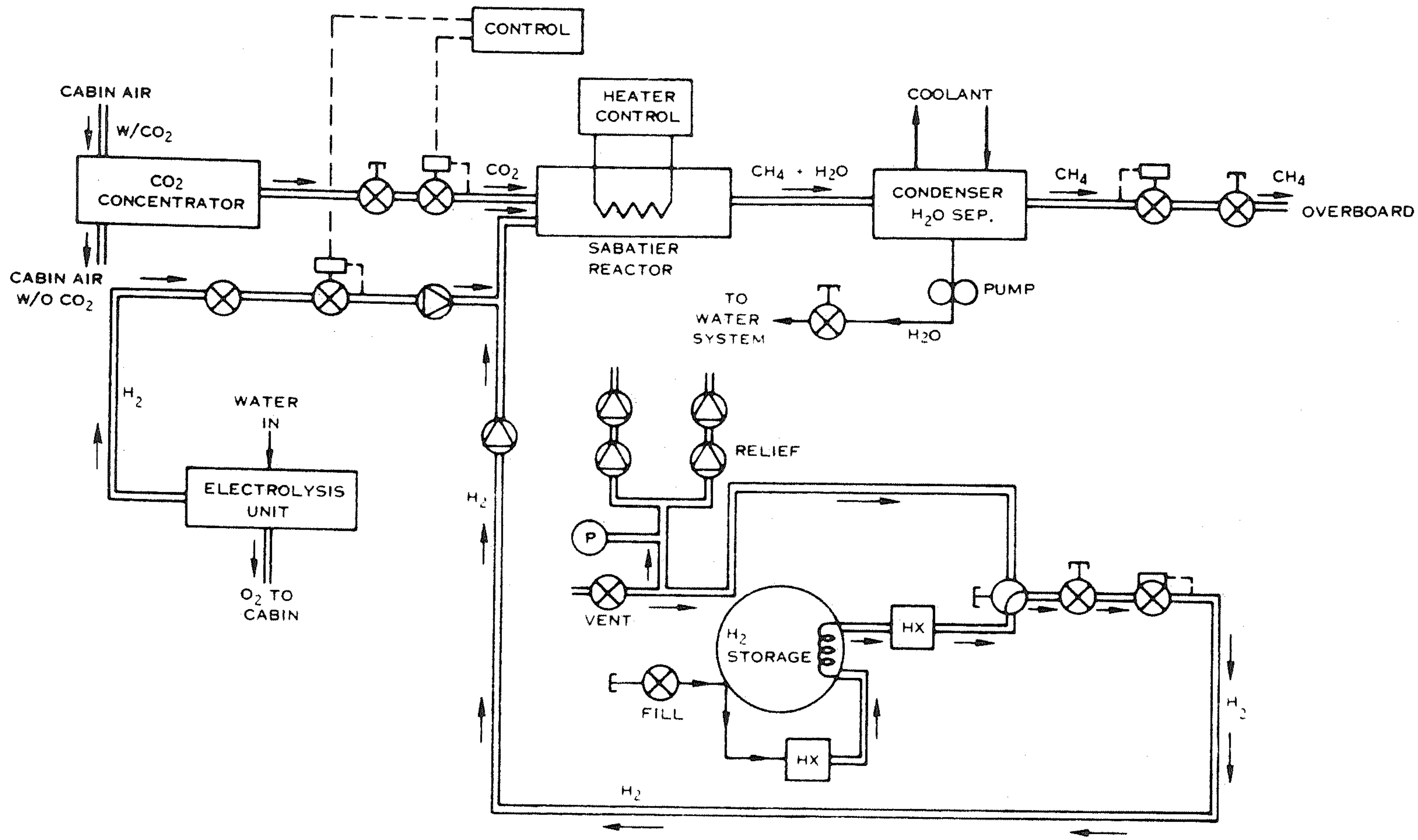

Figure 7. Sabatier CO_2 Reduction with Methane Dump Concept.

TABLE 8 - EVALUATION SUMMARY - CO_2 REDUCTION - MISSION B

CRITERIA		Bosch	Sabatier - Methane Dump
Absolute	Performance	Good	Good
	Safety	Fair	Fair
	Avail/Conf.	Good	Very good
Primary	Reliability	Fair	Fair
	Crew time	Good	Very good
	Equivalent Weight	Very good	Poor
		Selected	Eliminated

The total Bosch system includes the steam desorbed resin carbon dioxide concentrator, the Bosch reactor, and the gas circulation water electrolysis concept. This system is described schematically in figure 8.

The Bosch system is a hydrogenation process and uses a single carbon dioxide reduction reactor operating at 1200° F. During normal operation of the reduction section, a reactor gas stream circulates through the catalytic reactor, the regenerative heat exchanger, the condenser-separator, the compressor, and back to the reactor. As the gas circulates, carbon dioxide (from the concentrator) and hydrogen (from electrolysis) are added, and water generated by the reaction is removed (after condensation) to the water management system. Within the reactor, water vapor and carbon are formed on a steel wool catalyst. Carbon is removed from the system by periodic replacement of the carbon-loaded catalyst cartridge.

An infrared instrument measures carbon dioxide partial pressure in the loop and, at a low concentration limit, signals a solenoid valve to let in more carbon dioxide. Hydrogen is added to maintain the selected total pressure. Heat from the exothermic reaction is rejected to the condenser coolant.

Atmosphere Contamination Control

Atmospheric contamination control is used to limit the concentration of trace gases, biological microorganisms, and wet and dry particulate matter in the cabin atmosphere to acceptable levels so that the health and comfort of the crew are safeguarded. Representative gaseous contaminants which require processing by the contamination control system are listed in table 9 along with their generation rates and tentative space maximum allowable concentrations.

<u>Mission A-contaminant control selection.</u> - It is anticipated that only two contaminant control systems could be developed in time to meet the 1975-1977 flight date. There are:

1. Non-regenerable charcoal with catalytic oxidation
2. Catalytic oxidation with sorption

A regenerable charcoal concept is presently in the research phase but is not expected to be available by the 1975-1977 time period.

Table 10 shows the evaluated ratings for the two candidate concepts.

There are two safety hazards inherent in the use of non-regenerable charcoal. The first of these and the least critical is the combustibility of charcoal. A more important hazard posed by charcoal is its ability to support bacterial growth, especially when loaded with adsorbed organic materials.

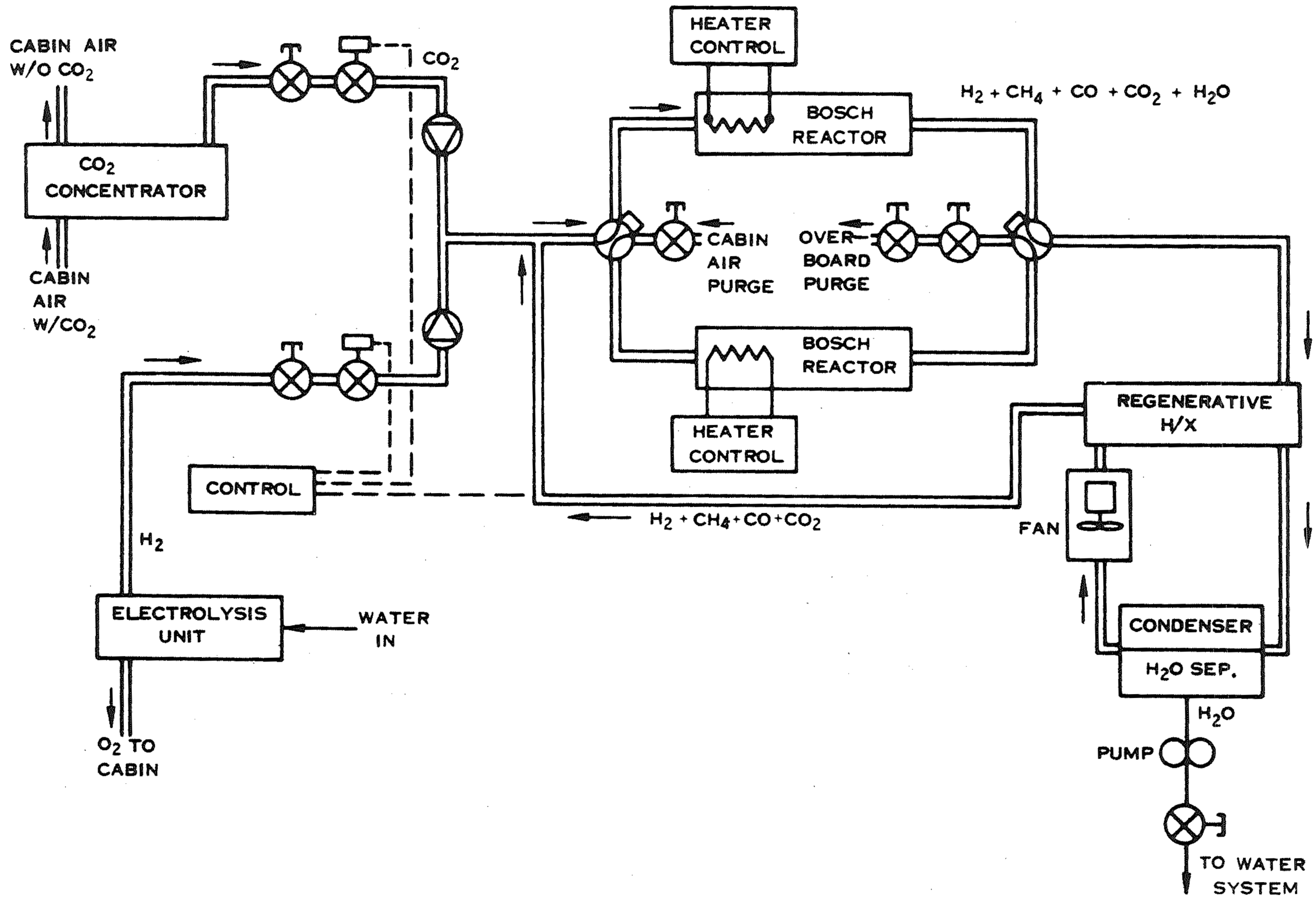

Figure 8. Bosch CO_2 Reduction Concept.

TABLE 9. - TRACE GAS CONTAMINATION MODEL

Contaminant	Production rate		Allowable Concentration		Principal toxic effect	Process rate	Equilibrium concentration
	Biological	Equipment	TLV	SMAC			
	lb/hr	lb/hr	ppm	ppm		lb/hr	ppm
Acetaldehyde, CH_3CHO	8.24×10^{-8}		200	40	Irritant	3.4	0.0002
Acetone, CH_3COCH_3	1.82×10^{-7}		1 000	200	Narcotic	3.4	0.0295
Ammonia, NH_3	2.36×10^{-4}		50	10	Irritant	53.5	7.75
Benzene, C_6H_6 [a]		1.41×10^{-5}	25	5	Narcotic - blood poison	3.4	1.63
n-Butanol, $C_4H_{10}O$	1.08×10^{-6}		100	20	Narcotic - irritant	3.4	0.0128
Butyric Acid, $C_4H_8O_2$	6.22×10^{-4}		39	8	Irritant	9000	0.298
Carbon Monoxide, CO	9.20×10^{-6}	1.08×10^{-5}	50	10	Blood poison	3.4	6.26
Cyclohexane, C_6H_{12} [a]		1.30×10^{-6}	300	60	Narcotic	3.4	0.0136
Dichlorodifluoromethane, CCl_2F_2 [b]		3.60×10^{-5}	1 000	200	Narcotic	3.4	2.62
Ethanol, C_2H_6O	3.31×10^{-6}		1 000	200	Narcotic - irritant	3.4	0.676
Hydrogen, H_2	7.27×10^{-6}	2.91×10^{-5}	30 000	30 000	Asphixiants	3.4	152.0000
Hydrogen sulfide, H_2S	4.15×10^{-9}		10	2	Irritant	3.4	0.0001
Methane, CH_4	1.17×10^{-4}	2.52×10^{-5}	53 000	53 000	Asphixiants	3.4	79.0000
Methanol, CH_3OH	1.25×10^{-6}	1.78×10^{-5}	200	40	Narcotic - irritant	3.4	5.42
Methylene chloride, CH_2Cl_2 [a]		3.60×10^{-5}	500	100	Narcotic	3.4	3.76
Pyruvic acid, $C_3H_4O_3$ [a]	1.73×10^{-4}		2.5	0.5	Irritant	9000	0.0331
Toluene, C_7H_8 [a]		1.20×10^{-5}	200	40	Narcotic - blood poison	3.4	1.159
Vinyl chloride, C_2H_3Cl		9.90×10^{-5}	500	100	Narcotic	3.4	13.800

a. Scaled from MOL
b. Same as methylene chloride

TABLE 10. - EVALUATION SUMMARY - CONTAMINANT CONTROL - MISSIONS A AND B

CRITERIA		Nonregenerable charcoal/catalytic oxidation	Catalytic oxidation/sorption
Absolute	Performance	Good	Good
	Safety	Fair	Very good
	Avail./Conf.	Good	Good
	Power	Good	Fair
Primary	Reliability	Very good	Very good
	Crew time	Fair	Very good
	Equivalent Weight	Poor	Very good
		Eliminated	Selected

The comparison of system weights and power shown below indicates that a non-regenerable charcoal system is considerably heavier than catalytic oxidation/sorption but requires about 50 watts less power.

Candidate	Power (watts)	Fixed wt. (lb)	180 Days Spares (lb)	180 Days Expendables (lb)
Non-regenerable charcoal	165	58	20	685
Catalytic oxidation/sorption	211	89	10	67

Although Mission A is a power limited system, the weight and safety advantages of catalytic oxidation with sorption outweigh the small difference in power, and it is selected for this mission.

This system is shown in figure 9. The catalytic oxidizer is the main contaminant removal device, with various sorbents employed to remove specific contaminants that cannot be satisfactorily removed in the oxidizer. The catalyst recommended is 20 percent palladium on alumina, operating at 700° F. The process rate through the catalyst bed is 3 cfm. The catalyst beds, which may be operated singly or in parallel, are oversized to allow for catalyst poisoning. No particular effort is made to prevent catalyst poisoning.

The main sorbent bed, which processes 50 cfm, and the catalytic oxidizer pre-sorber are intended to remove ammonia only. For this purpose, copper-sulfated Sorbeads are recommended, but other sorbents are available. The catalytic oxidizer post-sorbent recommended is lithium carbonate because of its demonstrated ability to sorb acid gases such as hydrogen chloride, chlorine, and hydrogen fluoride, which may be formed in the oxidizer.

Electrical power is used to heat the oxidizer. A heating element is installed in each oxidizer and heats both the process flow and the catalyst bed directly. A regenerable heat exchanger is also included in the oxidizer. Normal temperature control is achieved by an on-off heater controller that responds to catalyst bed temperature. In the event a catalyst bed fails, the heater is simply shut off and the flow is diverted to the good oxidizer.

Mission B-contaminant control selection. - Since the power difference in the two evaluated concepts is less critical for the Mission B system, the choice of catalytic oxidation with sorption remains the best selection. Descriptions of the concept characteristics and operation are the same as described for Mission A.

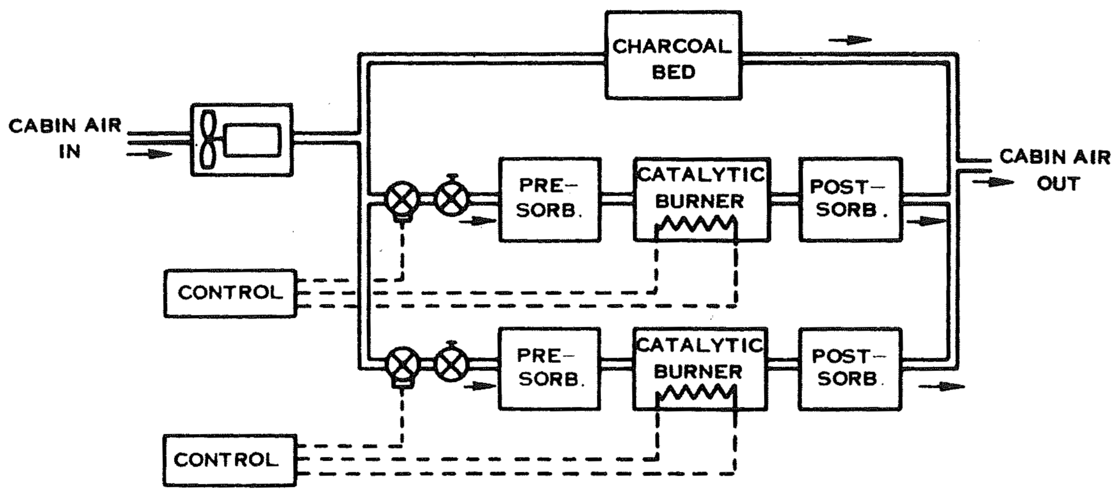

Figure 9. Catalytic Oxidation/Sorption Concept.

Temperature and Humidity Control

To assure crew comfort, both cabin temperature and relative humidity must be controlled and proper cabin ventilation must be provided. Cabin temperatures between 65° F and 75° F can be selected by the crew. Relative humidity is normally regulated to 55 ± 5 percent.

Mission A-temperature and humidity control selection. - There are four basic systems considered for temperature and humidity control:

1. Condenser/reheat
2. Variable speed fan
3. Air bypass
4. Separate condenser and cooler

Evaluations of these candidates for the mission evaluation criteria are shown in table 11. The variable speed fan and air bypass systems are the two most competitive concepts. Power and weight descriptions for these are given below.

Candidate	Power (watts)	Fixed wt. (lb)	180 Days Spares (lb)	180 Days Expendables (lb)
Variable speed fan	998	466	365	0
Air bypass	882	502	353	0

The powers shown are for use with condensing heat exchangers with integral wicking. Integral wicking has slightly lower pressure losses, hence lower power losses than face wicking. The wicks are internal, however, and when the wicks clog, the whole heat exchanger must be replaced. In spite of this, because of the lower power (350 watts), the integral wick concept is chosen for Mission A.

Greater power saving can be realized by other system changes. If more of the electronic equipment is cold-plate-cooled rather than gas cooled, it is anticipated that an additional 200 watts could be saved. Lower gas cooled loads may change the selection of the air bypass system, but the major change would be towards less power.

The air bypass system shown in figure 10 uses a bypass valve controlled by varying the coolant flow.

Full fan flow is maintained at all times so that supplementary ventilation flow is not needed at high temperature or partial load conditions. An integral wick condensing heat exchanger is used.

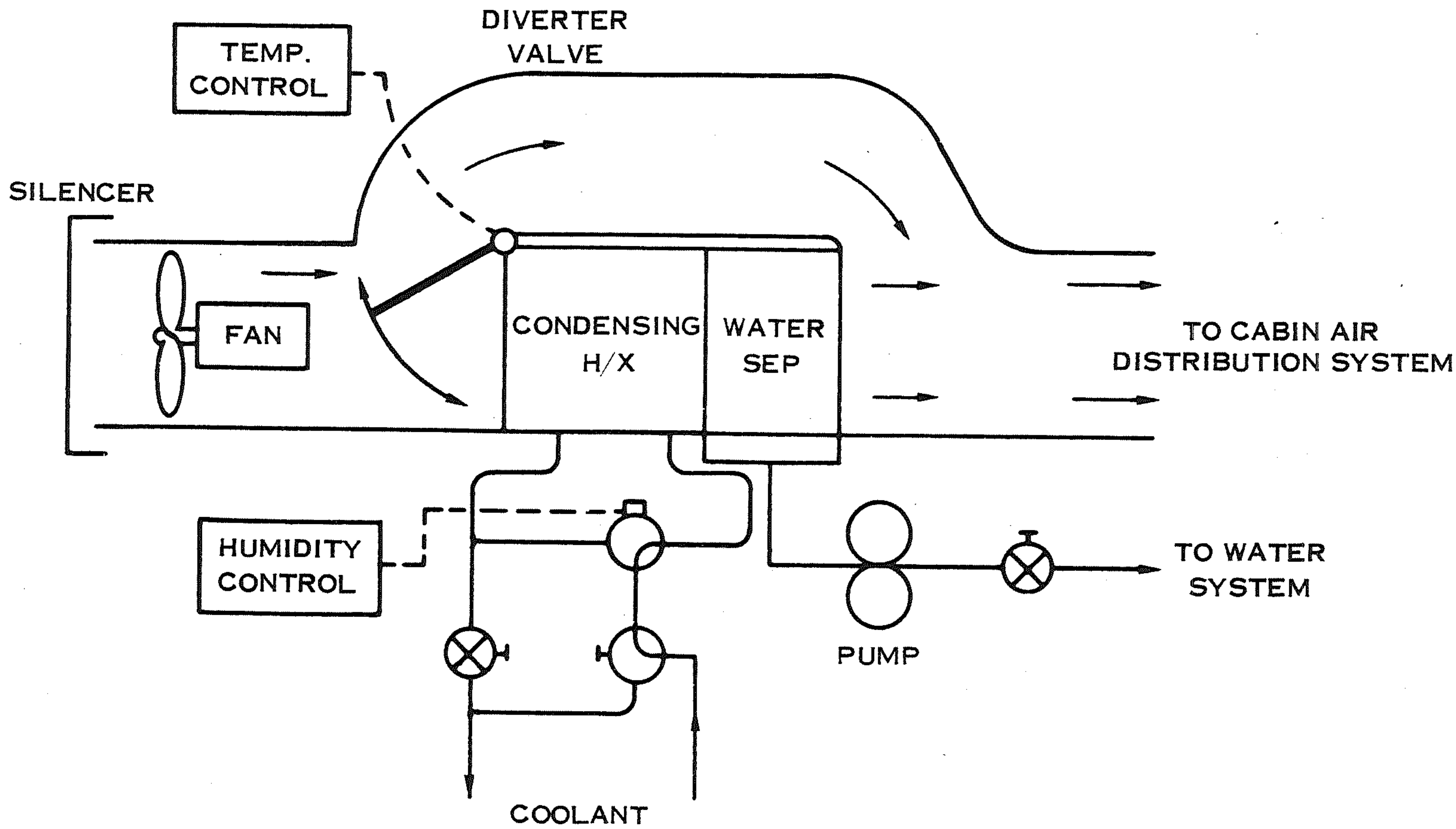

Figure 10. Air-Side Bypass Concept.

Mission B-temperature and humidity control selection. - Power being less critical, the variable speed fan concept shows better ratings for the criteria in table 11 than the air bypass concept. Use of face wicking, despite its slightly higher pressure drop, is now acceptable and offers the advantage of individual wick replacement rather than replacing the entire heat exchanger. The evaluation is summarized in table 12. The selected concept, shown in figure 11, uses a variable speed fan controlled by a temperature controller. Cabin temperature is controlled by varying the air flow through the heat exchanger. Cabin relative humidity is controlled by varying the coolant flow through the heat exchanger.

Maximum airflow (at maximum fan speed) occurs at the maximum cabin load condition at a 65° F temperature condition. The variable speed operation of the fan motor is obtained by varying both frequency and voltage as a function of temperature setting. This method is necessary to obtain efficient low speed performance. The system uses a face wick type condensing heat exchanger.

Water Management

The water management subsystem is used to collect and purify waste water and to store and deliver potable water for use on demand. In performing this function, the subsystem is constrained by the following contamination control requirements: 1) water produced by the subsystem must be sterile and free of organic and inorganic toxic material, 2) stored water must remain sterile, 3) it must be possible to service the equipment routinely without contaminating the stored water, 4) service operations, such as changing filters and removing sludge, should not contaminate the crew or the atmosphere, and 5) in the event of contamination of the water supply, there must be a means of complete and rapid system sterilization.

The waste waters which require processing by the water reclamation subsystem are listed below with their maximum daily average production or use rates. The equivalent required hourly processing rate is based on 18 hours of processing per day.

Source	Daily rate (lb/day)	Hourly rate (lb/hr/18-hr day)
Urine	29.70	1.65
Sweat and respired moisture	47.60	2.64
Washwater	102.60	5.70
Urinal flush	54.00	3.00
	233.90	12.99

Following are discussions of the selections for the water storage and water reclamation portions of the water management subsystem.

TABLE 11. - EVALUATION SUMMARY - TEMPERATURE AND HUMIDITY CONTROL - MISSION A

CRITERIA		Reheat			Variable speed fan		Air bypasss		Separate condenser and cooler		
		Integral wick	Face wick	Free moisture	Integral wick	Face wick	Integral wick	Face wick	Integral wick	Face wick	Free moisture
Absolute	Performance	Good	Very good	Very good	Good	Good	Good	Good	Fair	Fair	Fair
	Safety	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
	Avail./Conf.	Good	Good	Very good	Good	Good	Good	Good	Good	Good	Very good
Primary	Power	Good	Good	Good	Good	Good	Very good	Good	Good	Good	Good
	Reliability	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
	Crew time	Fair	Fair	Fair	Good	Good	Good	Good	Good	Good	Good
	Equivalent Weight	Fair	Good	Fair	Good	Good	Good	Good	Poor	Poor	Poor
		Eliminated	Eliminated	Eliminated	Eliminated	Eliminated	Selected	Eliminated	Eliminated	Eliminated	Eliminated

TABLE 12. - EVALUATION SUMMARY - TEMPERATURE AND HUMIDITY CONTROL - MISSION B

	CRITERIA	Reheat			Variable speed fan		Air bypass		Separate condenser and cooler		
		Integral wick	Face wick	Free moisture	Integral wick	Face wick	Integral wick	Face wick	Integral wick	Face wick	Free moisture
Absolute	Performance	Good	Very good	Very good	Good	Good	Good	Good	Fair	Fair	Fair
	Safety	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
	Avail./conf.	Good	Good	Very good	Good	Good	Good	Good	Good	Good	Very good
Primary	Reliability	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
	Crew time	Fair	Fair	Fair	Good	Good	Good	Good	Good	Good	Good
	Equivalent Weight	Fair	Good	Fair	Good	Good	Good	Good	Poor	Poor	Poor
		Eliminated		Eliminated					Eliminated	Eliminated	Eliminated
Secondary	Contamination		Very good		Poor	Very good	Poor	Very good			
	Interfaces		Poor		Good	Good	Good	Good			
	Flexibility		Fair		Good	Good	Good	Good			
	Growth		Good		Good	Good	Good	Good			
	Noise		Fair		Very good	Good	Poor	Poor			
	Volume		Very good		Very good	Very good	Good	Good			
	Power		Good		Good	Good	Very good	Good			
			Eliminated		Eliminated	Selected	Eliminated	Eliminated			

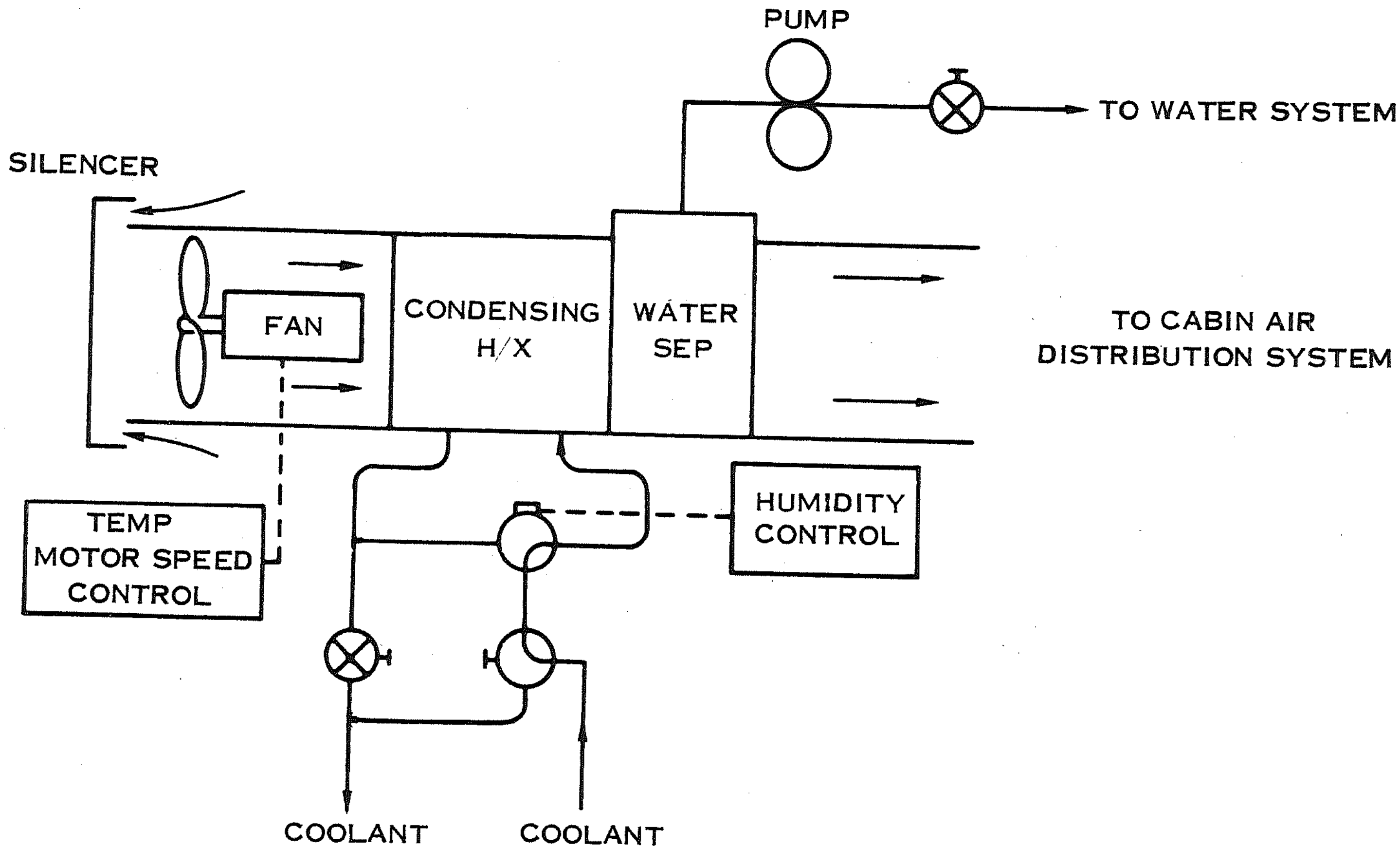

Figure 11. Variable Speed Fan Concept.

Water storage selections. - Unlike the AILSS, which uses bladderless tanks for potable water storage, the Mission A and B systems use bladder tanks. Bladderless tanks will not be available for these pre-AILSS time period missions.

Mission A water reclamation selection. - The water reclamation processes satissying the absolute requirements are shown in table 13 and are rated for each criterion shown. Note, however, that reverse osmosis is evaluated for washwater and condensate only, and that multifiltration is evaluated for condensate only; neither is suitable for processing urine. Use of these concepts must be limited to those applications which employ a separate urine or urine and washwater processing unit.

Referring to table 13, the most important primary criterion is power. Six of the concepts can be considered competitive on the basis of power: vacuum distillation/compression, vacuum distillation/thermoelectric, flash evaporation/compression/pyrolysis, vapor diffusion/compression, multifiltration, and reverse osmosis. The first four are distillation processes. Vapor diffusion/compression stands out as superior because of performance, safety (because of its positive bacteria control) and low crew time. It is therefore selected as the urinal water processing system.

Shown below are quantitative data for the leading low power concepts. The weights shown are based on 180 day resupply.

Candidates	Power, watts	Initial Launch equivalent weight, pounds				
		Power	Basic weight	Expendable 180 days	Spares 180 days	TEW 180 days
Multifiltration (condensate only)	13	8	113	73	38	232
Reverse osmosis (condensate and washwater)	80	47	123	48	56	274
Vapor diffusion/compression (urinal H_2O + RO reject)	770	452	306	92	65	915
Vapor diff./compr. (all water)	1550	912	398	122	80	1462

An examination of these data shows a significant weight and power advantage by using vapor diffusion/compression for urinal water processing coupled with reverse osmosis for condensate and washwater processing. This is, therefore, the selected water reclamation system for Mission A. A schematic of this concept is shown in figure 12.

TABLE 13. - EVALUATION SUMMARY - WATER RECLAMATION - MISSION A

	CRITERIA	Vacuum distillation /compression	Vacuum, distillation /thermoelec.	Vacuum distillation /pyrolysis	Flash evaporation/compression/pyrolysis	Flash evaporation /pyrolysis	Air evaporation (open)	Air evaporation (closed)	Vapor diffusion	Vapor diffusion/ compression	Electro- dialysis	Multi-filtration x	Reverse Osmosis xx
Absolute	Performance	Good	Good	Good	Good	Good	Very good	Very good	Very good	Very good	Very good	Very good	Very good
	Safety	Good	Good	Good	Good	Good	Unacceptable	Good	Very good	Very good	Good	Good	Fair
	Avail./conf.	Good	Fair	Good	Good	Good	Good	Good	Good	Good	Fair	Very good	Good
							Eliminated				Eliminated		
Primary	Power	Fair	Fair	Poor	Fair	Poor		Poor	Poor	Fair		Very good	Very good
	Reliability	Good	Good	Good	Good	Good		Very good	Very good	Good		Very good	Very good
	Crew time	Poor	Fair	Fair	Fair	Fair		Fair	Very good	Very good		Very good	Very good
	Equivalent Weight	Very good	Very good	Poor	Good	Poor		Poor	Poor	Good		Very good	Very good
		Eliminated	Eliminated	Eliminated	Eliminated	Eliminated		Eliminated	Eliminated	Selected		Eliminated	Selected

x Ratings for condensate processing only

xx Ratings for condensate plus washwater only

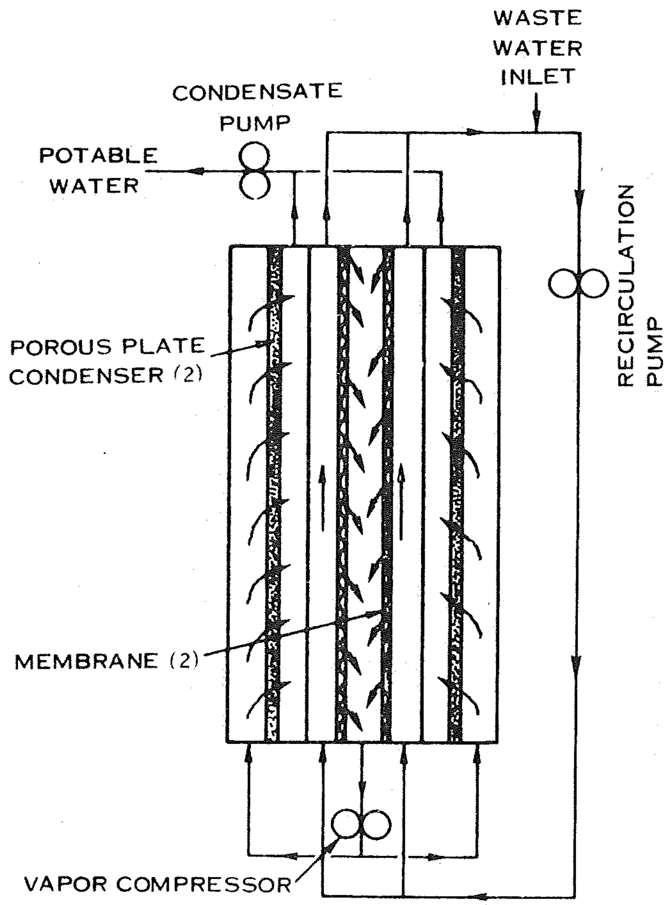

Figure 12. Typical Vapor Diffusion/Compression Module Arrangement.

Reverse osmosis uses high pressure to force water from a solution through a semipermeable membrane into a less concentrated solution. The osmotic pressure required depends on the concentration of the waste water. For washwater, a low initial osmotic pressure of about 20 psi is required. As water is extracted, the concentration of impurities increases, and with it, the osmotic pressure. The pressure required to achieve a desirable recovery efficiency and process rate is 100 psi for 80 percent and 185 psi for 90 percent recovery.

Reverse osmosis residuum is mixed with urinal water and processed further in a vapor diffusion/compression unit. Vapor diffusion/compression is an ambient pressure distillation process in which water evaporates through a membrane, is compressed, and condenses on a porous metal condenser-separator. The heat of condensation, made available by the compression process, is used to evaporate the urine. The semipermeable membrane prevents the passage of solids and other contaminants, including microorganisms, into the condenser. The unit, one module of which is depicted in figure 13, is composed of several membrane evaporator-condenser modules. In addition, the system employs a urine preheater, a condenser coolant loop, a circulation tank, pumps, pre-treatment tanks, a compressor, and post-treatment equipment.

The overall recovery efficiency is 99.3 percent. This leaves about 558 pounds of waste water residuum that must be disposed of over a 180 day period. With resupply capability, it can be stored in tanks on-board the spacecraft and, subsequently, transferred to the resupply vehicle for return to earth. Another approach would be to process the residuum in the waste management system along with the other wastes.

<u>Mission B water reclamation selection.</u> - Because Mission B does not represent a power critical situation, power may be dropped from the primary criteria. With that in mind, table 14 was constructed to show the evaluation for Mission B. The competitive water reclamation concepts are vapor diffusion and vapor diffusion/compression. Vapor diffusion was selected primarily on the basis of lower system weight made possible by utilizing waste heat from the Brayton cycle power source. All other criteria were rated equally or better for vapor diffusion than for vapor diffusion/compression.

This process is in effect the same as the vapor diffusion/compression process described for the Mission A water reclamation subsystem. These processes differ only in the provision in the Mission A system for recovering the heat of condensation by the method of vapor compression. The vapor diffusion concept is shown schematically in figure 14.

Consideration was given to utilizing reverse osmosis, a lower weight and power subsystem, to reclaim the condensate and wash water. A weight reduction of 216 pounds for 180 days was realized by adding reverse osmosis to process this part of the waste water. Less critical restrictions on power, increased system complexity, increased expendables, poorer reliability, and increased crew time, however,

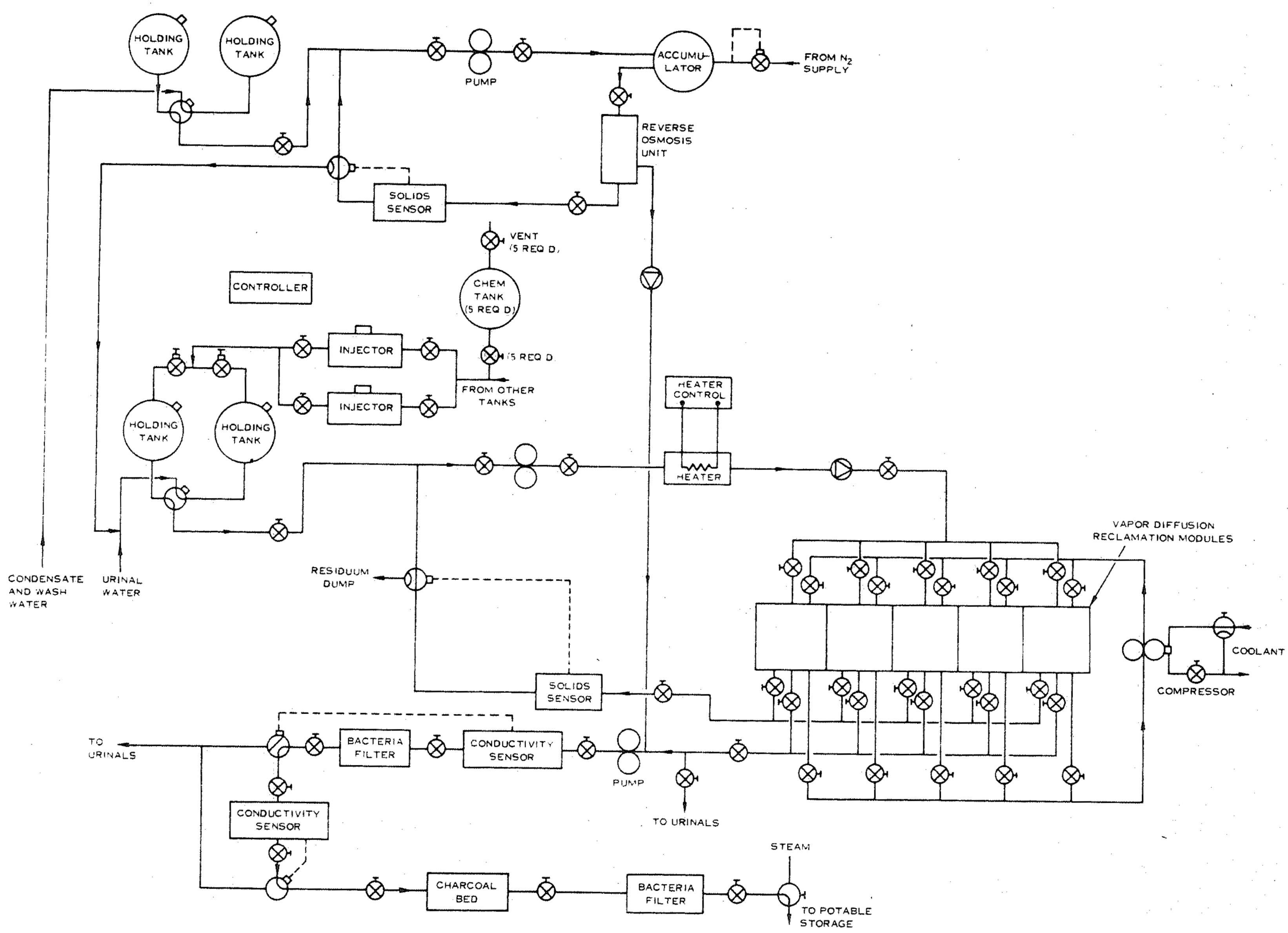

Figure 13. Vapor Diffusion/Compression Concept.

TABLE 14. - EVALUATION SUMMARY - WATER RECLAMATION - MISSION B

	Criteria	BRAYTON CYCLE DESIGNS											
		Vacuum distillation/ compression	Vacuum distillation/ thermoelec.	Vacuum distillation/ pyrolysis	Flash evaporation/compression/pyrolysis	Flash evaporation/ pyrolysis	Air evaporation (open)	Air evaporation (closed)	Vapor diffusion	Vapor diffusion/ compression	Electro-dialysis	Multifil-* tration	Reverse** osmosis
Absolute	Performance	Good	Good	Good	Good	Good	Very good	Very good	Very good	Very good	Unacceptable	Very good	Very good
	Safety	Good	Good	Good	Good	Good	Unacceptable	Good	Very good	Very good	Good	Good	Fair
	Avail./Conf.	Good	Fair	Good	Good	Good	Good	Good	Good	Good	Fair	Very good	Good
							Eliminated				Eliminated		
Primary	Reliability	Good	Good	Good	Good	Good		Very good	Very good	Good		Very good	Very good
	Crew time	Poor	Fair	Fair	Fair	Fair		Fair	Very good	Very good		Very good	Very good
	Equivalent Weight	Very good	Very good	Good	Fair	Good		Good	Very good	Fair		Very good	Very good
		Eliminated	Eliminated	Eliminated	Eliminated	Eliminated		Eliminated	Selected	Eliminated		Eliminated	Eliminated

* Ratings for condensate only

** Ratings for condensate plus washwater only

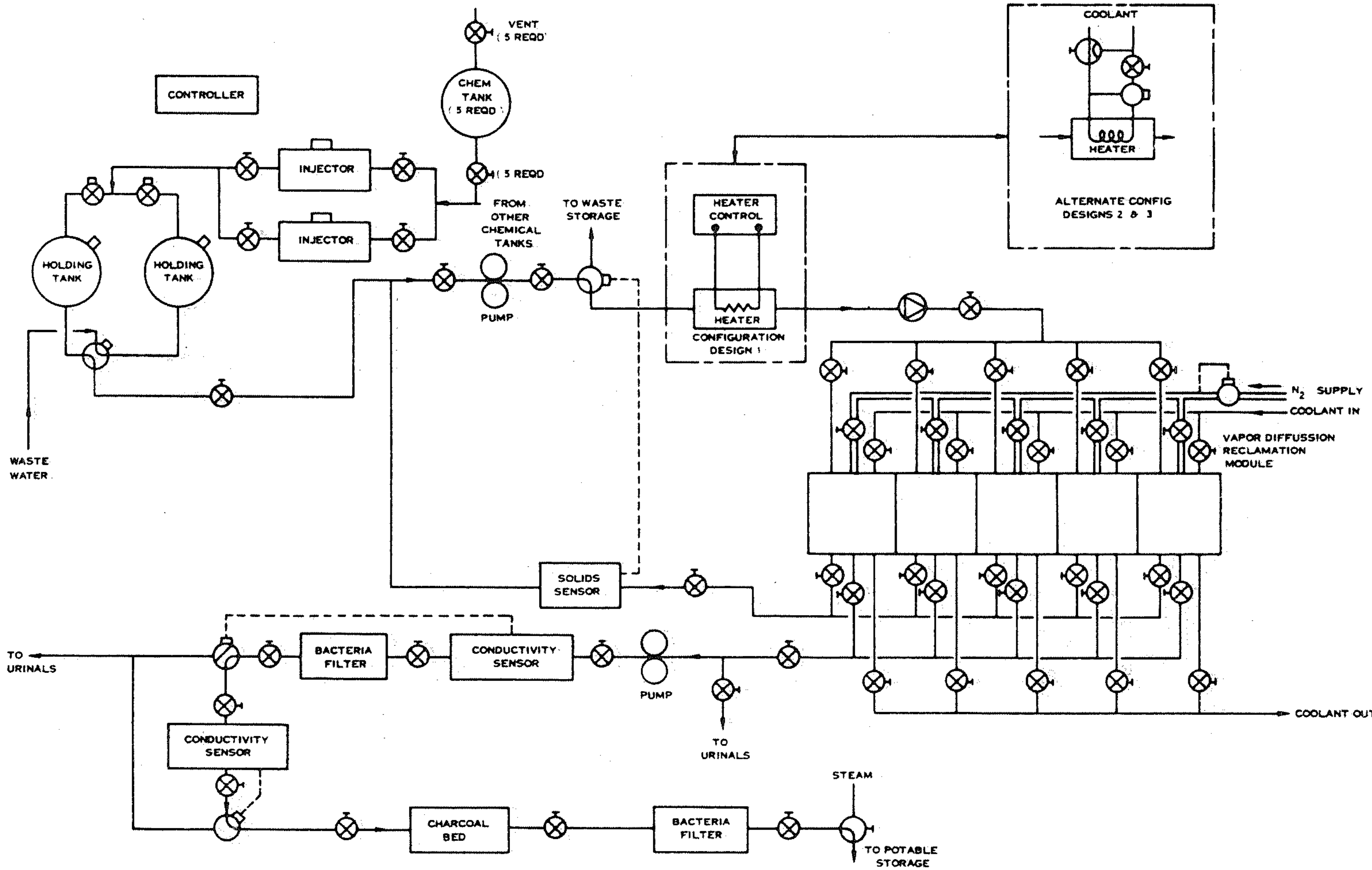

Figure 14. Mission B Water Reclamation System

outweighed any savings in weight offered by the inclusion of reverse osmosis. A vapor diffusion system was therefore selected to provide total waste water processing for Mission B.

Waste Control

The waste control subsystem provides for collection, treatment, and storage and/or disposal of all solid and liquid wastes, including the collection and transfer of raw urine to the water management system. Other subsystem requirements include elimination of odors, aerosols, and toxic gases as well as waste sterilization and storage or elimination of waste materials.

The waste categories and daily quantities that require processing by the waste control subsystem are presented in the following table:

	Solids (lb/day)	Liquids (lb/day)
Feces	0.99	2.25
Urine solids	1.53	1.53
Tissue wipes	0.99	--
Food packaging	1.81	--
Unused food	0.99	1.26
Debris	0.08	--
Facial and cranial hair	Negligible	
Vomitus	Occurs at infrequent intervals	
	6.39	5.40

Total waste products = 11.43 lb/day
Solids - 56 percent
Liquids - 44 percent

Of the concepts initially considered as potential waste processing methods, only those satisfying the AILSS absolute requirements are retained for a complete evaluation. Biodegradation, irradiation, freezing, vacuum drying utilizing separate functions, and wet oxidation were eliminated from further consideration because they fail to meet the absolute requirements. Biodegradation and wet oxidation are rejected because of unacceptable availability/confidence. Irradiation and vacuum drying utilizing separate functions, which have an inherent requirement for manual transfer of feces, are rejected on the basis of the established ground rules which preclude this type of operation. Freezing processes, which inhibit microorganisms production rather than provide their destruction, are rejected for safety considerations.

Mission A waste control selection. - Table 15 summarizes the Mission A waste control evaluation of concepts with acceptable absolute characteristics. Integrated vacuum drying and liquid germicide addition are the prime candidates, because they require significantly lower power, as shown in the following table based on 180-day resupply.

	Power watts	Initial launch equivalent weight, pounds				
		Power equiv.*	Basic	Expendables	Spares	Total
Liquid germicide	300	135	71	645	240	1091
Integrated vacuum drying	191	86	82	600	150	918
Integrated vacuum decomposition	1400	669	354	330	60	1413
Flush flow O_2 incineration	1000	480	372	790	75	1717
Pyrolysis/batch incineration	1400	669	372	465	80	1586

* Includes heat rejection penalty

Crew time for both of these concepts is entirely satisfactory. Equivalent weight is very low for both concepts. Hence, liquid germicide addition and integrated vacuum drying have very good primary criteria evaluations, and a choice cannot be made at this level. Table 15 also shows that overall secondary criteria ratings are very nearly equal, although liquid germicide is considered poor in more areas than integrated vacuum drying. Reinspection of absolute criteria emphasizes that the major rating difference between the two concepts is in availability/confidence, which is much higher for integrated vacuum drying. Thus, the integrated vacuum drying concept is selected for Mission A because development of a low power, high performance unit is much more likely.

A schematic diagram of the selected integrated vacuum drying concept is shown in figure 15. Waste matter is dried to ten percent water content to stop microorganism activity and to allow safe storage. Elimination of manual transfer operations is achieved by collecting, treating, and storing wastes in a common container. After defecation (or collection of other waste materials), a gate valve seals the container, which is then evacuated to 1.0 psia by a vacuum pump before exposure to space vacuum. Incorporation of the vacuum pump reduces the cabin air loss. A fan provides process air flow. The fan must be sized to pass an adequate air flow through the container when it is full. A filter is required to retain solids and liquids but allow passage of the process air.

Efficient operation can be provided by adding a motor-driven slinger to break up the fecal matter and centrifugally transfer it to the container walls. Because a good heat transfer surface is provided, application of a thermal energy source to the container is not required. Cabin air maintains the container/fecal matter interface at a temperature sufficient to dry the waste to a bacteriostatic condition.

TABLE 15. - EVALUATION SUMMARY - WASTE CONTROL - MISSION A

	Criteria	Liquid germicide addition	Integrated vacuum drying	Integrated oxygen decomposition	Flush for oxygen incineration	Pyrolysis/ batch incineration
Absolute	Performance	Good	Good	Good	Good	Good
	Safety	Fair	Fair	Good	Good	Good
	Avail/conf	Fair	Very good	Good	Good	Good
Primary	Power	Very good	Very good	Fair	Fair	Fair
	Reliability	Very good	Very good	Good	Good	Good
	Crew time	Good	Good	Very good	Very good	Very good
	Equiv. weight	Very good	Very good	Good	Poor	Fair
				Eliminated	Eliminated	Eliminated
Secondary	Contamination	Poor	Fair			
	Interfaces	Very good	Good			
	Flexibility	Fair	Good			
	Growth	Fair	Fair			
	Noise	Good	Fair			
	Volume	Poor	Poor			
		Eliminated	Selected			

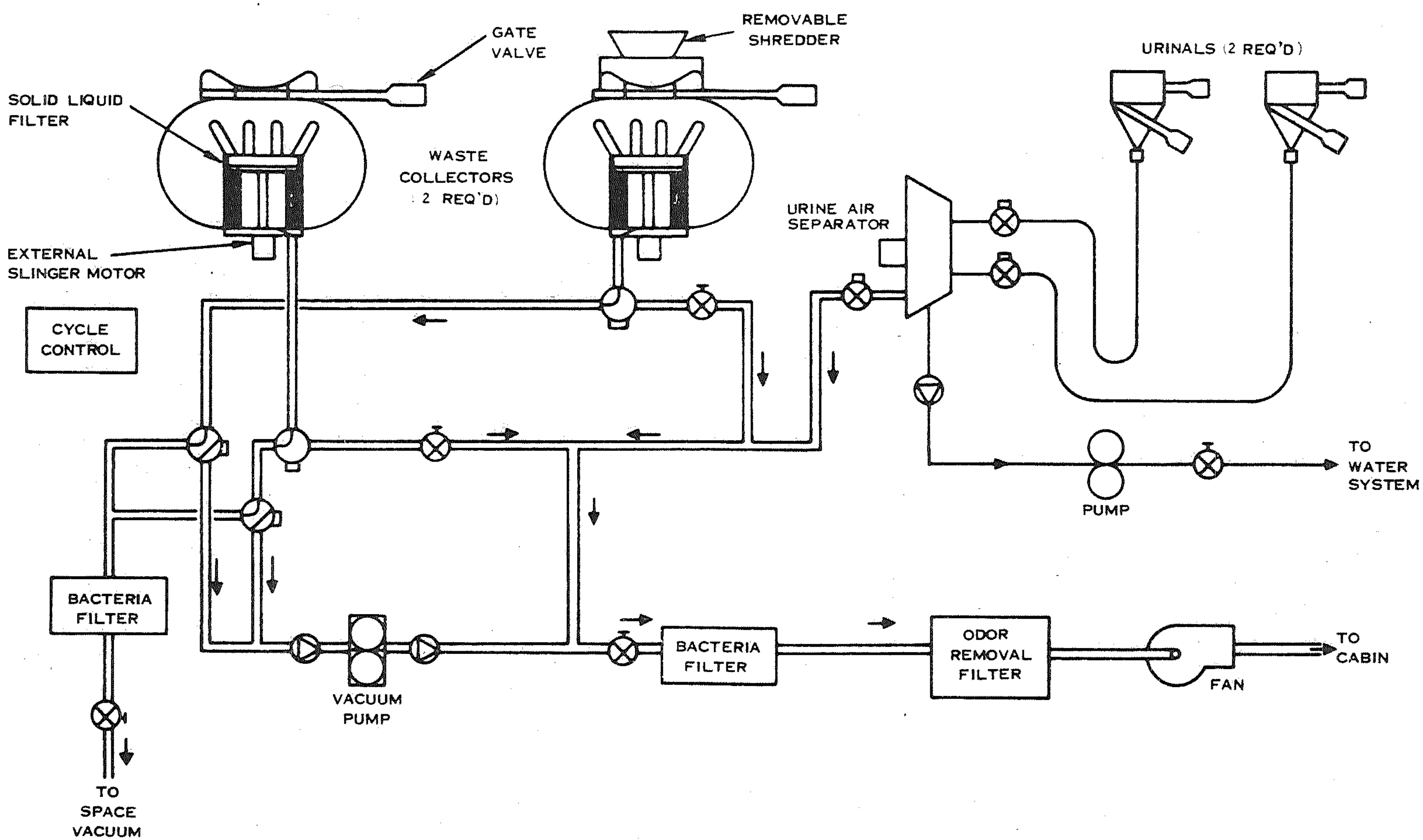

Figure 15. Integrated Vacuum Drying Concept.

Mission B waste control selection. - Table 16 summarizes the Mission B waste control evaluation. With power no longer a primary consideration, the liquid germicide addition and integrated vacuum drying concepts still have the most attractive primary characteristics. However, with satisfactory reliability and equivalent weight and superior crew time, the integrated vacuum decomposition concept is also attractive. The situation is reversed for the secondary criteria, where integrated vacuum decomposition is clearly superior. In fact, liquid germicide addition and integrated vacuum drying are considered poor in at least one area, implying difficult development problems.

The integrated vacuum decomposition concept is selected to avoid these problems and for its superior safety and crew time.

The selected concept, shown schematically in figure 16, totally sterilizes and decomposes collected waste matter. The treatment process consists of three steps. First, heating to 250° F for 30 minutes ensures sterilization of the wastes. Opening the vacuum vent valve then flashes contained water to space as a vapor. Finally, heating to 1200° F with the vent valve still open pyrolytically decomposes the waste matter, and the resulting gases vent to space. After the unit cools, a crew member vacuums the residual ash (approximately 12 percent of the total waste matter processed) into a storage container, where it remains until removed during resupply.

Crew Provisions

All of the crew provisions concepts selected for AILSS are available for Missions A and B. The concepts selected for Mission A include a freeze-dried diet, a whole body shower and disposable clothing. Mission B uses the same food and washing method, but reusable clothing is selected.

Instrumentation

A data management approach to fault detection and isolation similar to the AILSS was selected. This approach, using computerized fault isolation is virtually automatic. Since the basic equipment can be made available for Missions A and B, it is therefore selected for these missions. It is anticipated, however, that somewhat less sophisticated fault isolation techniques will be possible for the earlier flight dates. Some crew participation will therefore be necessary.

TABLE 16. - EVALUATION SUMMARY - WASTE CONTROL - MISSION B

		Liquid germicide addition	Integrated vacuum drying	Integrated vacuum decomposition	Flush flow oxygen incineration	Pypolysis/ batch incineration
Criteria						
Absolute	Performance	Good	Good	Good	Good	Good
	Safety	Fair	Fair	Good	Good	Good
	Avail/conf	Fair	Very good	Good	Good	Good
Primary	Reliability	Very good	Very good	Good	Good	Good
	Crew time	Good	Good	Very good	Very good	Very good
	Equiv. weight	Very good	Very good	Good	Poor	Fair
					Eliminated	Eliminated
Secondary	Contamination	Poor	Fair	Very good		
	Interfaces	Very good	Good	Good		
	Flexibility	Fair	Good	Very good		
	Growth	Fair	Fair	Very good		
	Noise	Good	Fair	Very good		
	Volume	Poor	Poor	Good		
	Power	Very good	Very good	Fair		
		Eliminated	Eliminated	Selected		

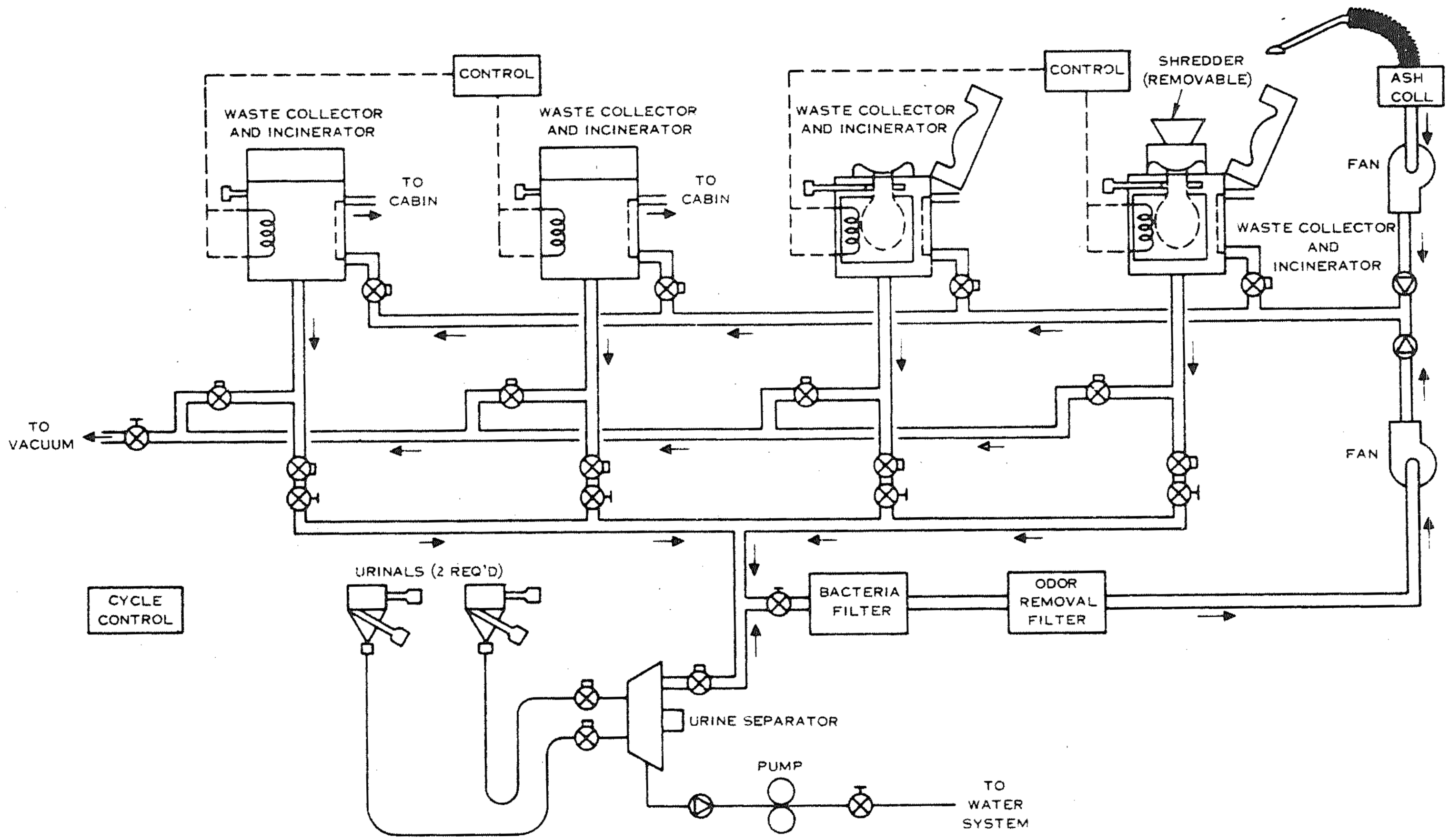

Figure 16. Integrated Vacuum Decomposition Concept.

EFFECTS OF MISSION PARAMETERS

There are a number of mission parameters that exert a major influence on the design of EC/LS equipment configuration, reliability, and weight. These include:

1. Resupply
2. Artificial gravity
3. Flight availability
4. Crew size

All of these items are influential to varying degrees in the configuration and design of the subsystems selected for both Mission A and Mission B. Resupply capability provides the ability to reduce the solar cell system power consumption at the expense of expendable weights. Artificial gravity, or rather its absence, is considered in subsystem designs involving two or more states of matter. Availability presents a major constraint for both Missions A and B. Crew size describes the requirements for supply and processing rates and the general configuration of equipment best suited to meet these requirements. The discussions which follow present the effects of these parameters on the Mission A and B systems.

Resupply

Provisions for vehicle resupply at 180-day intervals allows several advantages and opportunities which are not available otherwise to the AILSS mission. Those areas primarily affected by resupply are associated with expendables and spares and with the useful or extended life of vehicle life support items. The following list outlines the areas affected by periodic resupply.

1. Spares
2. Expendables
3. Limited life items
4. Maintenance
5. Recalibration
6. Possibility for abort
7. System effect

Spares. - Resupply has a fundamental and direct bearing on equipment spares requirements. As an example, consider the minimum mission duration of 720 days (2 years). This mission can be divided into four 180 day resupply segments. The vehicle is launched with the spares required to achieve the required reliability for the 180 day period. At the end of each period, an inventory of the unused spares is taken and only those items actually required to restock the spares inventory to its original level will be resupplied. Thus, the total number of additional spares to be resupplied is equal to the total number of spares used during the first three segments of the four-segment mission. There is a high probability that the number of spares used per segment is in the range of four to seven or, extended to the total mission, 12 to 20 spares to be resupplied.

Expendables. - Expendable items which include food, clothing, make-up oxygen and nitrogen, hydrogen, and water can be limited to the 180-day resupply period. Food is the largest expendable item accounting for some 40 percent of the EC/LS total equivalent weight on a 500 day mission. The food and all other expendables amount to approximately 5500 pounds for each 180 day resupply period. An effect that should be considered with regard to expendables is that of disposal. Weight and volume reduction of certain items such as food containers, unused food, feces, and urine solids becomes less critical since these may be disposed of at 180-day intervals and will not require accumulated vehicle storage for the entire mission. Use of lower performance but lower weight and power waste processing systems, such as vacuum drying, takes on increased importance.

Limited life items. - Those items subject to predictable degradation over the period of the total mission length are referred to as limited life items and may be replaced as necessary or at predetermined intervals coincident with the resupply schedule. Provisions and requirements for life limited items are reduced to a significantly shorter period of time allowing greater flexibility in their use and less stringent requirements for redundancy and spares.

Maintenance. - The maintenance approach may be modified for missions with a short (e.g. 180 days) resupply period. Certain failed equipment that would normally be considered as maintainable in flight may now be spared at a higher level. This approach would be desirable if a reduction in maintenance time is possible. Other influences on maintenance approaches occur with multiple installed redundancies. Launch weight may be reduced by not carrying (as installed redundancies) certain heavy spares. These spares may be supplied by the resupply vehicle on an as-required basis. Maintenance would then be required.

Recalibration. - Calibration of vehicle systems may be accomplished at the resupply intervals through standards inherent in or transported from earth as calibrated components by the resupply vehicle. For example, the major problem with polarographic oxygen sensors is that they are a limited life item and that their calibration changes with time, whether they are used or not used. It would now be possible to use these items which have a low weight, power, and volume by resupplying calibrated sensors every 180 days.

Possibility for abort. - The capability of resupply suggests the possibility of mission abort. With this option available, system failures requiring abort can be repaired or replaced upon return and vehicle reactivation. Failures requiring abort therefore need not imply total mission failure.

System effect. - The effect of resupply on Mission A total equivalent weight is that the launch weight is reduced by 17 337 pounds by the use of resupply every 180 days for the two year mission. In addition, 789 pounds of spares weight is saved by replacing only those items which fail during the 180 day period.

For Mission B, the launch weight is reduced by 12 846 pounds by the use of resupply every 180 days for the two year mission. In addition, 698 pounds of spares weight is saved by replacing only those items which fail during the 180 day period.

The weight saving of Mission B is less than Mission A because of the use of:

1. The Bosch CO_2 reduction unit
2. Reuseable clothing
3. Integrated vacuum decomposition unit

A detailed weight breakdown is presented in tables 2 and 3 of this report.

Total equivalent weight summary

	Launch weight (lb)	Two years total weight (lb)	180 day Expendable wt. (lb)
Mission A	14 885	32 262	5 716
Mission B	14 058	26 904	4 243

Artificial Gravity

The Mission A and B systems were designed for zero "g" conditions. Use of artificial gravity would greatly simplify some of the subsystems. General areas of simplification are:

1. Liquid/gas separation
2. Liquid/gas interface control
3. Maintenance
4. Subsystem concepts

Several subsystems become much easier to design and are more reliable due to liquid/gas separation by gravity. Examples of this are condensing heat exchangers that would not require wicks for phase separation and electrolysis cells that would use liquids instead of immobilized matrixes.

Active control of the interface position greatly simplifies the use of bladderless tanks. Quantity measurement is also simplified and more reliable. Resupply of cryogenic fluids becomes possible. Waste collection subsystems would change, completely eliminating fans and seals required for containment. A shower is a much simpler and lighter device since a forced air stream is not required.

Maintenance of liquid lines becomes much easier as lines can be easily drained, parts replaced or repaired, and the lines refilled. Gas can be bled from the lines at the "top" of the system. "Gas traps" are simpler and more reliable than "zero-g" type separators.

Time required to maintain components or subsystems will be shorter as the man can use both hands to work and can use gravity to brace himself.

Gravity will also lessen the contamination problem. Spilled liquids, large dust particles, dropped components, food crumbs, etc., will tend to settle out and fall to the "floor". A vacuum cleaner will be required for cleaning the floor but contamination will be much more localized. This localization could now make the use of systems which contain toxic fluids more practical by reduction of the containment problem. An example might be the circulating electrolyte electrolysis subsystem. Under "zero-g" conditions, loss of the electrolyte (KOH) into the cabin atmosphere would result in its dispersion over the entire vehicle by the gas stream. With gravity, any electrolyte leakage should be localized and special equipment could be added to contain leaks.

Systems which were not considered due to complexity of phase separation such as fused salt CO_2 reduction should be re-examined to see if they would become competitive with a gravity field available. Gravity would shorten the development leadtime so that systems of this type would be available earlier.

Waste Management would be greatly simplified in a gravitational field. Positive phase control would be possible for both liquid and solid wastes. The urine/air separator would not be required since gravity could be used to separate the liquid and gas. The fan would not be required for the collection of urine because gravity would direct the urine to the urinals. The water pump could also be deleted if the water system could be located "below" the urinals so that gravity could be relied upon to pump the urine.

A major change to the Waste Management Subsystem might be the deletion of rotating equipment; three of the four rotating components could be removed. System weight could be lowered and spares and power requirements reduced. The shape of the waste containers would probably change so that better utilization of the volume is possible. Gravity would direct the waste to the bottom of the container and the vacuum port could be placed near the "top" of the container so that liquid separator screens are not required. In addition some of the valving associated with deleted items could be removed. The largest change would be the increased reliability of the system.

For water reclamation, a conventional vacuum distillation system would be used. Boiling the waste water directly and using gravity to separate the condensate is the simplest approach since rotating surfaces would not be required. Pumps, liquid/gas separators, etc., would be eliminated, making the system more reliable.

A membrane evaporator is not necessary since vapor filtering may be located above the boiler. If used, membrane life would be much extended since it would not be clogged by the residue. Recovery efficiencies approaching 100% would be possible since solids would precipitate out of the urine residium in setting tanks.

In the power critical design, reverse osmosis would still be used as would vapor diffusion/compression. Since reverse osmosis is an all-liquid-phase system, and vapor diffusion/compression is a gas phase function, no gravity influence exists.

For CO_2 reduction, the Bosch subsystem should be easier to develop. The weight of the Sabatier-methane dump subsystem should be lighter because the hydrogen tanks can be easily refilled, reducing expendable weight. The tanks were considered expendables.

Gravity would eliminate the major problem of the wick feed water electrolysis subsystem. The problem of gas buildup in the cell, purging the cell, and separation of the gas is relatively simple if gravity is available. Other systems such as the circulating electrolyte system look much more attractive. Operation should be simpler; closer to commercial electrolysis cell operation. Systems can be easily drained for component repair or replacement. Leakage is not as serious, as "drip pans" can contain the corrosive fluid.

CO_2 concentration would be the least affected of the subsystems. The molecular sieve concentrator would not change for Mission A and the steam desorption subsystem would remain the same for Mission B. Liquid absorption does not appear attractive enough to warrant further development. Handling of gases and solids is preferred even with a gravity field.

Contamination control of noxious and toxic gases, and airborne bacteria contamination, will not be affected by gravity. Surface microbiological decontamination and debris will be easier to control as it will tend to settle out of the air stream. Dusting or vacuuming of the "floor" will be required to remove the debris.

Gravity will have a significant effect on the thermal and humidity control subsystem. Flow rates may be reduced as gravity induced convection will help in thermal control. Water separation from the condensing heat exchanger can be accomplished with gravity rather than wicks or rotary separators. This should considerably increase reliability. Power will increase, however, as the water must be blown off of the heat exchanger surface rather than be wicked off.

Subcritical O_2 and N_2 storage becomes very practical in a gravitational environment. No phase control devices are required. Resupply, using a "g" field to effect transfer, becomes a relatively simple operation. Fluid gauging is also much simpler and more reliable. For a low leakage vehicle (1.0 lb/day) such as AILSS, high pressure storage, however, would still be the best system as the amount of O_2 and N_2 to be resupplied is so small. For larger leakage rates, with resupply, subcritical cryogenic storage would be chosen as the weight savings would be substantial.

As an example, the estimated effect that gravity will have on the power limited Mission A is shown in table 17. Fixed weight and spares would decrease 592 lb, power would decrease 359 watts, and expendables would decrease 573 lb for each 1 80 day resupply period.

TABLE 17
MISSION A SYSTEM WEIGHT CHANGE WITH ARTIFICIAL GRAVITY*

	ΔWt. expendables (lb)	ΔWt. basic (lb)	Δspares (lb)	ΔPower (watt)
O_2 and N_2 storage	0	0	0	0
Water electrolysis	0	0	0	-326
CO_2 concentrator	0	0	0	0
CO_2 reduction	-342	0	0	0
Contamination control	0	0	0	0
Thermal and humidity		-176	-238	+147
Water reclamation	0	-103	-29	0
Waste management	-231	-14	-32	-180
TOTAL	-573	-293	-299	-359

*For each 180 day resupply period

Flight Availability

Table 18 presents a summary of the availability of each of the concepts considered. All of the flight dates are based on adequate funding being available on January 1, 1970.

TABLE 18
AVAILABILITY SUMMARY

Subsystem concept	Current development phase	Earliest flight date	Development problems
O_2/N_2 storage			
High press., steel	Complete*	1973	None
High press., fil. wound	Complete*	1974	Normal development
High press., titanium (N_2)	Complete*	1973	Normal development
Supercritical cryogenic/ thermal pressurization	Complete*	1974	Insulation techniques
Chlorate candles (O_2)	Prototype	1974	Control of the reaction at low usage rates.
Peroxides/superoxides (O_2)	Prototype	1976	High inherent wt. - unacceptable for long missions
Hydrogen peroxide (O_2)	Prototype	1976	Phase separation
Subcritical cryogenic/ thermal pressurization	Research	1977	Insulation techniques. Positive phase control.
N_2H_4/N_2O_4	Concept	1980	Safety - crew exposure to unreacted fuel and oxidizer
Subcritical cryogenic/positive expulsion	Research	1980	Bladders that will withstand flexing at cryogenic temps. for 2 years
Solid cryogenic (O_2)	Research	1982	On-demand supply
Nitric oxide decomposition	Concept	1982	Feasibility of reaction not demonstrated. No development being performed
Water electrolysis			
Wick feed	Prototype	1974	Requires O-g gas separator - gas dissolved in feed water causes shutdown.
Cabin air	Prototype	1976	Control of O_2 generation rate. Damage to electrolyte at low cabin humidity. Trace contaminant carry over.

*Available now, but work on improved versions continues.

TABLE 18 (Continued)
AVAILABILITY SUMMARY

Subsystem concept	Current development phase	Earliest flight date	Development problems
Ion exchange resin	Prototype	1976	No proof of endurance. Method to detect and isolate H_2 leaks.
Gas circulation	Research	1977	No life testing run.
Ion exchange membrane	Prototype	1977	Requires gas separator. No endurance proven. Materials compatibility, current distribution and coolant dist. problems.
Circulating electrolyte	Prototype	1977	Plastic construction presents fire and atm. contam. problem. Needs gas separation device.
Rotating unit	Prototype	1977	Rotating connections and seals. Electrolyte containment when unit stops rotating.
CO_2 removal			
Molecular sieve	Complete	1974	Normal development
Solid amine	Prototype	1976	Delivery purity not established
Membrane final filter	Research	1976	No life testing.
Steam desorbed resin	Research	1977	Delivery purity not established.
Electrodialysis	Prototype	1977	Delivery purity not established. Req. devel. of humidifier.
H_2 depolarized cell	Research	1978	Delivery purity not established. Delivery CO_2 contains H_2 - need means to react or separate

TABLE 18 (Continued)
AVAILABILITY SUMMARY

Subsystem concept	Current development phase	Earliest flight date	Development problems
Membrane diffusion	Research	1978	No endurance testing done. Possible poisoning of water condensate.
Mechanical freezeout	Research	1978	Delivery purity not established . Miniature rotating machinery development.
Carbonation cell	Research	1979	Delivery purity not established. Materials problems.
Liquid absorption	Research	1980	Phase separation problems.
CO_2 reduction			
Sabatier - CH_4 dump	Complete	1974	Normal development
Sabatier - CH_4 cracking	Research	1980	Basic research required.
Sabatier - C_2H_2 dump	Concept	1983	Practical laboratory model must be run.
Bosch	Prototype	1976	Carbon carryover from the reactor cartridge and carbon formation outside the cartridge.
Solid electrolyte	Research	1979	Requires devel. of non-catalytic Hx, compressor and reactor housing. Must find influence of oper. temp. on life and carbon form.
Fused salt	Research	198?	No proven design for O-g operation.
Atmosphere contamination control			
Nonregenerable charcoal	Complete	1974	Bacterial growth in charcoal
Catalytic oxidation -1 and 3	Complete	1974	Establish suitability of specific catalysts

TABLE 18 (Continued)
AVAILABILITY SUMMARY

Subsystem concept	Current development phase	Earliest flight date	Development problems
Nonregenerable sorbent	Research	1977	Selection of sorbents. Normal development
Regen. charcoal - 1 and 3	Research	1979	Normal development
Water reclamation			
Multifiltration	Complete	1973	Urea removal
Reverse osmosis	Prototype	1975	Membrane life. Need additional method to remove urea.
Air evaporation, open	Prototype	1975	Microbiological and trace cont. control
Air evaporation, closed	Prototype	1974	Reduce power requirement
Vac. dist./pyrolysis	Prototype	1974	Reduce power requirement
Rot. Vapor Compression	Prototype	1975	Seal and compressors for long life
Vac. dist. thermoelectric	Research	1977	Presently short life of thermoelectric elements in series
Flash evap./compres./pyrol.	Research	1977	Evap-sep. needs development
Flash evap./compres./pyrol.	Research	1977	Evap-sep. development
Vapor diffusion	Prototype	1976	Membrane life
Vapor diff./compression	Research	1977	Membrane, compressor devel.
Water storage			
Bladder tanks	Complete	1972	Bladder life
Bladderless tanks	Prototype	1977	O-g capability development required
Body cleaning			
Disposable wipes	Complete	1972	Excessive weight

TABLE 18 (Continued)
AVAILABILITY SUMMARY

Subsystem concept	Current development phase	Earliest flight date	Development problems
Reuseable wipes	Complete	1972	Little development required
Automatic sponge	Complete	1972	Normal development
Shower	Prototype	1975	Some integration development
Immersion bath	Prototype	1979	Not effective, needs development
Sauna	Concept	198?	Not effective
Clothing			
Disposable	Research	1977	Selection and treatment of materials to meet fire safety requirements
Reuseable, incl. washer	Concept	1977	Needs cleaning method. Ultrasonic U.V. could be studied. Need devel. of O-g washing machine.
Waste control			
Vac. drying, sep. func.	Prototype	1974	Unaccep. due to requirement for manual transfer
Integ. vacuum drying	Prototype	1972	Normal devel.
Freeze wet waste	Concept	1977	Unacceptable for safety considerations.
Liquid germicide	Research	1977	No devel. has been done, require development of safe germicide.
Flush flow O_2 incineration	Prototype	1977	Normal development
Pyrol/batch incineration	Prototype	1977	No devel. done yet Normal devel.
Integ. vac. decomposition	Prototype	1976	Normal devel.

TABLE 18 (Concluded)
AVAILABILITY SUMMARY

Subsystem concept	Current development phase	Earliest flight date	Development problems
Gamma irradiation	Research	1979	Unacceptable due to requirement for manual transfer of waste.
Wet oxidation	Research	1980	Need practical means for efficient expulsion and filtration, reduction in residue quantities. O-g oper. not demonstrated.
Biodegradation	Research	198?	Aerobic is slow and produces noxious gases. Aerobic used commercially, but little devel. has been accom. for flight use.
Beta-excited x-ray irrad.	Research	198?	Unacceptable due to requirement for manual transfer.
Crew provisions (diet)			
Dried	Complete	1973	No devel. req., but unacceptable to crews for long duration flights.
Frozen	Prototype	1977	Req. devel. to determine most economical combination of freezer temp. and packing material.
Freeze dried	Complete	1975	Reduce packaging weight
Liquid	Prototype	1978	Need tests to determine physical effects of long-term use and crew acceptability.
Chemical	Research	198?	Same as liquid

The table also shows the current status of each concept and the major development problems involved. The entire projection is based on delineating several stages of development through which any concept must pass. These five stages were designated concept phase, research phase, prototype development phase, flight hardware phase, and qualification phase.

Current status. - The first step in estimating the flight readiness of a concept is to determine its current development status. As a prerequisite, the five development stages were defined as follows:

Concept phase: A hardware concept or process has been suggested but no laboratory work has been done to confirm its feasibility. More specifically, there is some element that differentiates the concept from similar concepts, and no experimental work has been done on this "differentiating element" following its suggestion. Analytical calculations may be rough or may include detailed computer analysis.

Research phase: In the early part of this phase, feasibility of the concept is confirmed by laboratory experimental work, which must involve those components ("essential components") used to implement the differentiating element. In the later part of this phase, essential components have been combined to form an integrated system, which is being tested to determine component interactions and system characteristics. This must involve actual, rather than simulated, component interface connection and simultaneous operation. Components may be made of any material and connections may be flexible tubing.

Prototype development phase: The early part of this phase is similar to the "pilot plant" stage in development of a commercial chemical process. Components are fabricated from materials that could be used in the final flight version, and considerable attention has been given to component packaging. The pilot unit is limited in that it must be scaled up from its fractional capacity to handle the full load in an actual space mission. This is the most probable time for use as an in-flight experiment. The later part of this phase involves a scaled-up version of the pilot unit. It is designed to support a crew of several men. This unit is usually heavier than the final flight version, and certain noncritical automatic control features may be manually simulated. This unit is often used in a manned spacecraft simulation chamber.

Flight hardware phase: This is a development stage involving a flight design developed for a specific preflight hardware test program.

Qualification phase: This final stage involves fabrication and performance and vibration testing of actual flight hardware for a specific flight hardware program. At completion of this stage, a concept is ready for flight evaluation.

Development projection. - Once a concept is identified with its present development phase, its future development must be projected through subsequent phases. The time element in development projection is especially difficult to forecast with consistency among concepts. The approach used to minimize this difficulty is to designate "standard" time periods for each development phase. Standard time periods were defined as follows:

Concept phase	1 year
Research phase	4
Prototype development phase	5
Flight hardware phase	3
Qualification phase	1
Total development period	14 years

These standard time periods are then modified to predicted actual time periods by considering the influence of simplifying and complicating factors. Simplifying factors include development work on a related flight concept, existence of a commercial version, and freedom from all but routine development problems. Complicating factors include anticipated problems with zero gravity phase separation, materials, high temperature, and component integration. Additional factors are the number of essential components, complexity of essential components, and maintenance and control considerations.

Flight readiness dates. - Adding the projected time from current status to final qualification to the current date gives the projected flight readiness dates shown in table 18. Because these dates are based on ample and continuous funding beginning early in 1970, many of them may be too early. Nevertheless, this does not limit their usefulness, because they are intended to assess potential availability rather than to predict actual availability.

Crew Size

Large crew size will have some effect on equipment selection but the primary effect will be on equipment modularity.

Subsystem selection. - Equipment changes will be in the area of contaminant control and water management. The expendable trace contaminant sorbent material should be replaced with a regenerable charcoal system. Large expendable quantities will therefore be eliminated.

In the area of water management it is desirable to reduce process penalties (in weight) by adding a reverse osmosis stage for washwater and condensate processing. The significantly large quantities of these waters result in a total equivalent weight decrease which more than compensates for the increased system unreliability.

The large quantities of wet wastes (food wastes and urine sludge, but not necessarily considering fecal water) produced by very large crews can provide large quantities of water. Water reclaimed from these wastes may be electrolyzed to produce oxygen for leakage make up, and also provide a source of oxygen expended during extravehicular activity operations.

Modularity. - With the advent of large crew size, the question of whether to provide single, large subsystems or to provide smaller modularized subsystem to perform the major EC/LS functions arises. If large functional subsystems are provided, the weight and size of the individual components becomes excessive and spare components are too large to handle easily. In order to reduce the weight and size of the spares, repairs will be made on a piece-part level. That is, seals, valve seats, bearings, etc., will be replaced instead of components. This will necessitate longer repair times because the valves, fans, etc. will have to be disassembled.

In a modular design, multiple units perform the necessary functions. If one module fails, the system operates in a degraded mode until repairs can be made.

A detailed modularity study of all subsystem must be made to determine the optimum modularity for each function considering such factors as:

Growth of function
Space available
Weight and size
Maintenance time
Instrumentation requirements
Number of compartments
Commonality
Interfaces

While this is not possible without a detailed description of the crew, the vehicle, or the mission, certain general comments can be made.

Compartmentation of the vehicle will be necessary with large crews. The decision to modularize the functions of cabin temperature control, humiduty control and contamination control will be influenced by vehicle configuration and compartmentation.

It is probable that the sensible heat generation rates will be independent of CO_2 and contamination water and will vary widely in each compartment. In order to conserve fan power each compartment will have an individual temperature control unit and ventilation system. Coolant will be pumped to each compartment for thermal control rather than the gas. The temperature control function is therefore modularized to a level depending on configuration.

It will be desirable to provide humidity control with a centralized system. This would minimize the number of components and keep the number of water separators to an absolute minimum. The major problem with this is the large power required for transport within the vehicle and the large duct size.

Based on an approximate humidity control flow of 50 cfm per man, the optimum duct diameter for a 50 man crew is about 18 inches.

Trace contaminant control of CO_2 and trace gases will be most efficiently accomplished by a central system consisting of a catalytic oxidizer, sorbent and concentrator. This flow will be directed to each compartment.

The basic CO_2 removal subsystem concept would not change for larger crew sizes but one or two additional modules would be used to eliminate subsystem downtimes. However, the repair time for this modularization approach will also increase as more and larger components are required.

Since a central unit is indicated for humidity and contaminant control, the degree of modularity may be based on maintenance and weight considerations. Other functions which fit into the same category are oxygen generation, water reclamation, and to some degree, waste management.

Power requirements. - Large crew sizes will require large amounts of EC/LS power. This is of major importance to the power generation system if there are constraints of maximum solar panel size (for Mission A), or available quantities of radioisotope for the Brayton cycle (for Mission B).

Power requirements for a nine man crew are approximately 1.5 kW per man, considering EC/LS power and other vehicle power required by the crew. About 50 percent of this power requirement is necessary for oxygen generation, temperature control, and water reclamation and is directly proportional to crew size. The remaining power requirements, as for lighting, communication, heat transport, etc. become more efficient on a per man basis. A 100 man station power requirement should therefore be of the order of 100 kW, with a power per man factor reduced to 1 kW per man.

An approximate equation to be used for EC/LS and crew dependent vehicle power is

$$P = 0.75\ N + 2.25\ N^{1/2}$$

where P is power in kilowatts, and N is the number of men.

PARAMETRIC DATA

The total equivalent weight for concepts considered for the AILSS study as a function of mission duration and power supply is presented for both six and nine man crews in figures 17 through 63.

Several cautionary notes must be made with respect to the use of these curves. First, the curves present subsystem data and do not reflect system integration considerations. The weight of certain thermal control and water management equipment is not shown and system commonality is not accounted for. Thus, the sum resulting from adding the weights for each selected concept does not necessarily equal the total system weight. Second, it should also be pointed out that the weights are for projected 1976-1980 state of the art and do not apply for missions in an earlier time period. Thirdly, power penalties are for the three AILSS designs, all solar cell power, isotope/solar cell power, and Brayton cycle power. The power penalty is 450 pounds/ electrical kW, and 50 pounds/isotope kW. These curves should not be used for other penalties. Finally, the curves for the water reclamation concepts reflect the processing rates indicated for six and nine men only, and extrapolation to other processing rates should not be attempted.

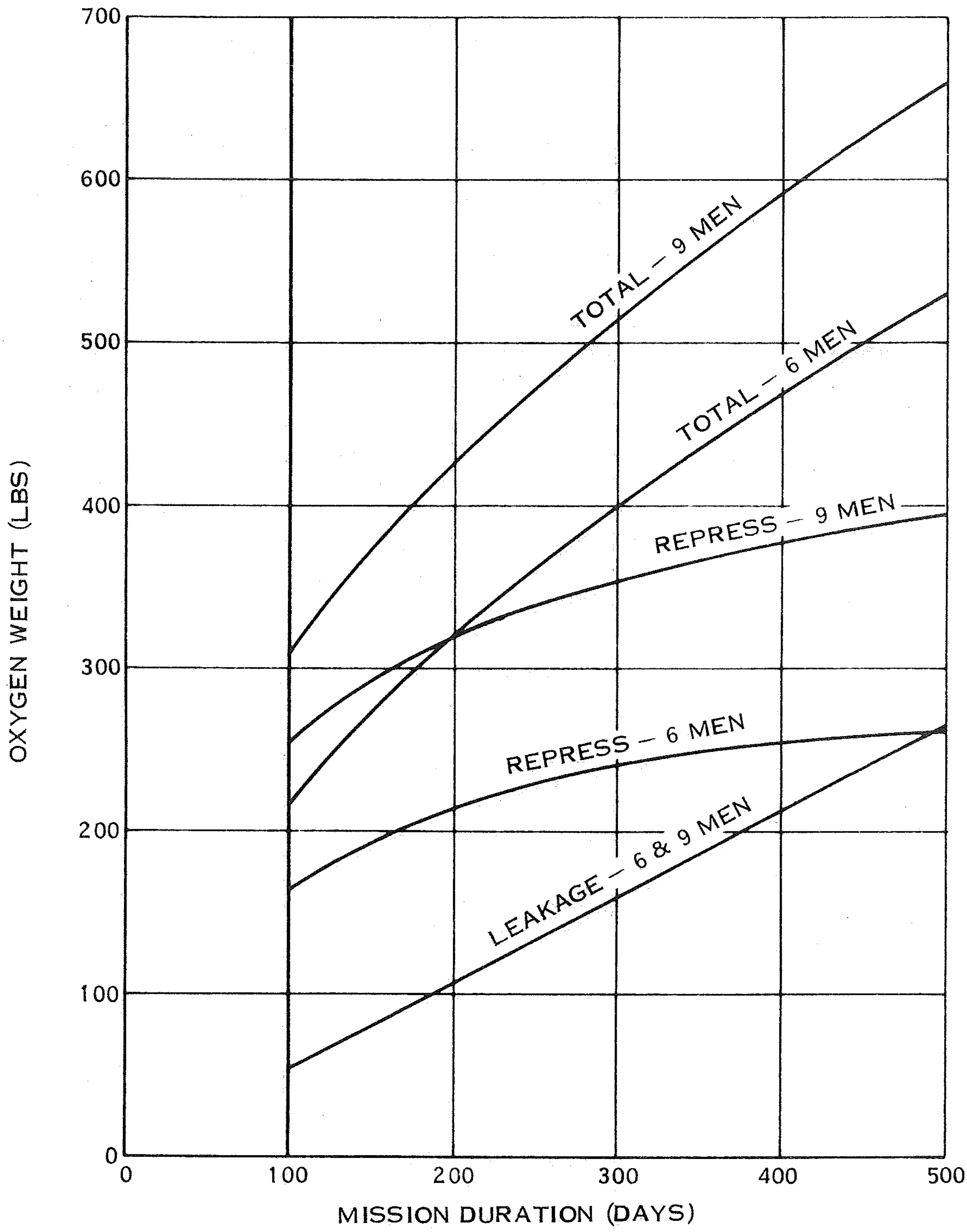

Figure 17. Oxygen Storage Requirements.

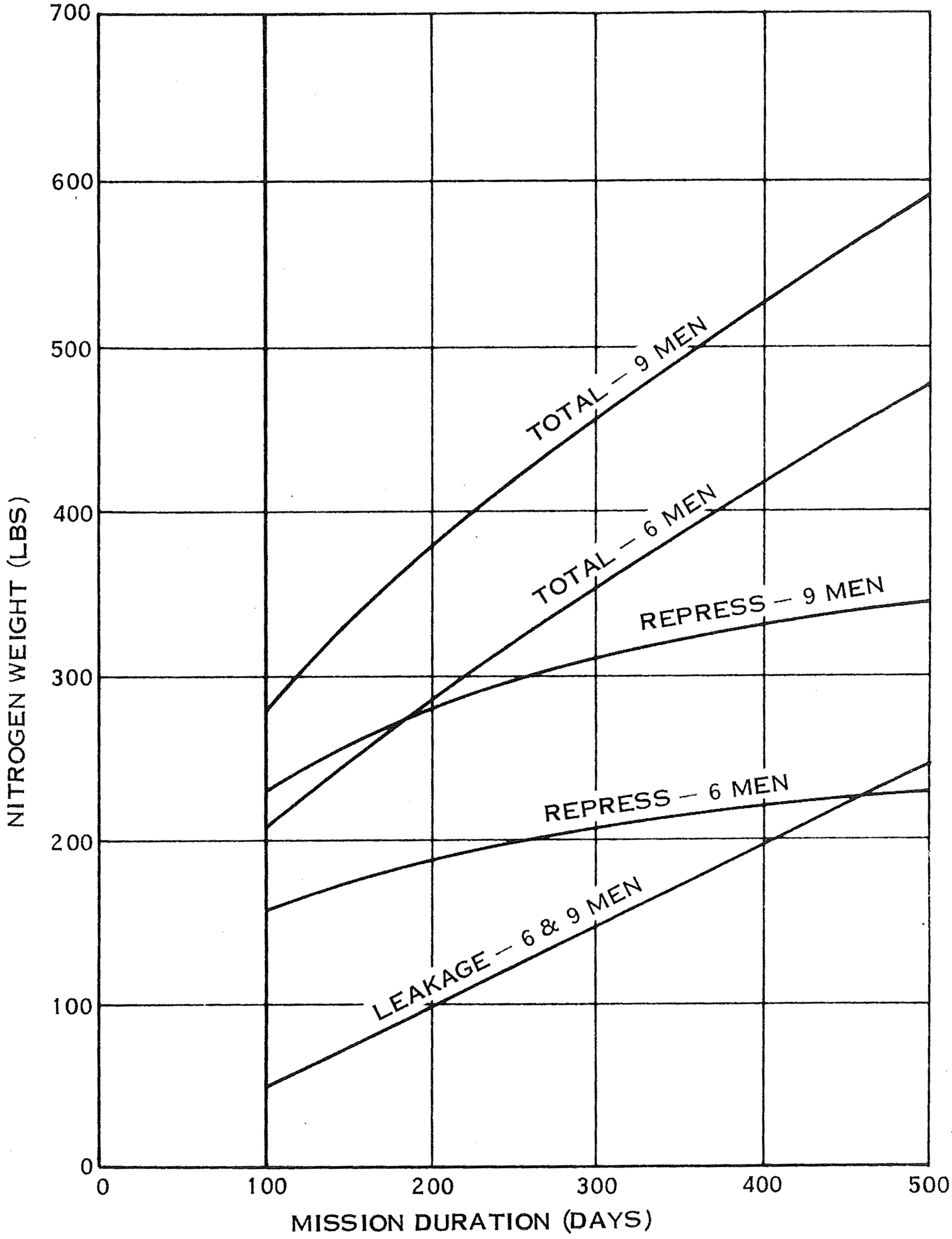

Figure 18. Nitrogen Storage Requirements.

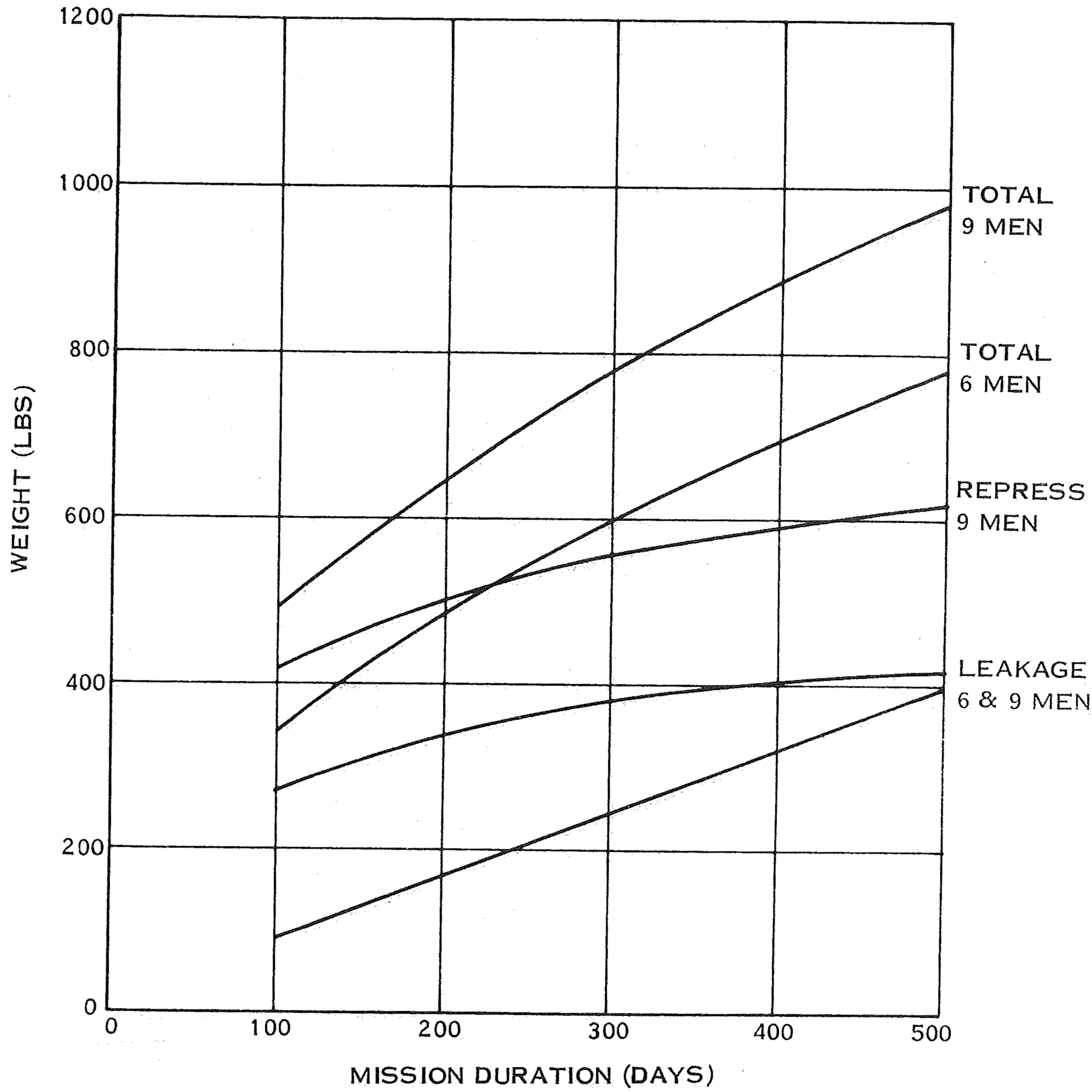

Figure 19. O_2/N_2 Storage - High Pressure Oxygen - Filament Wound.

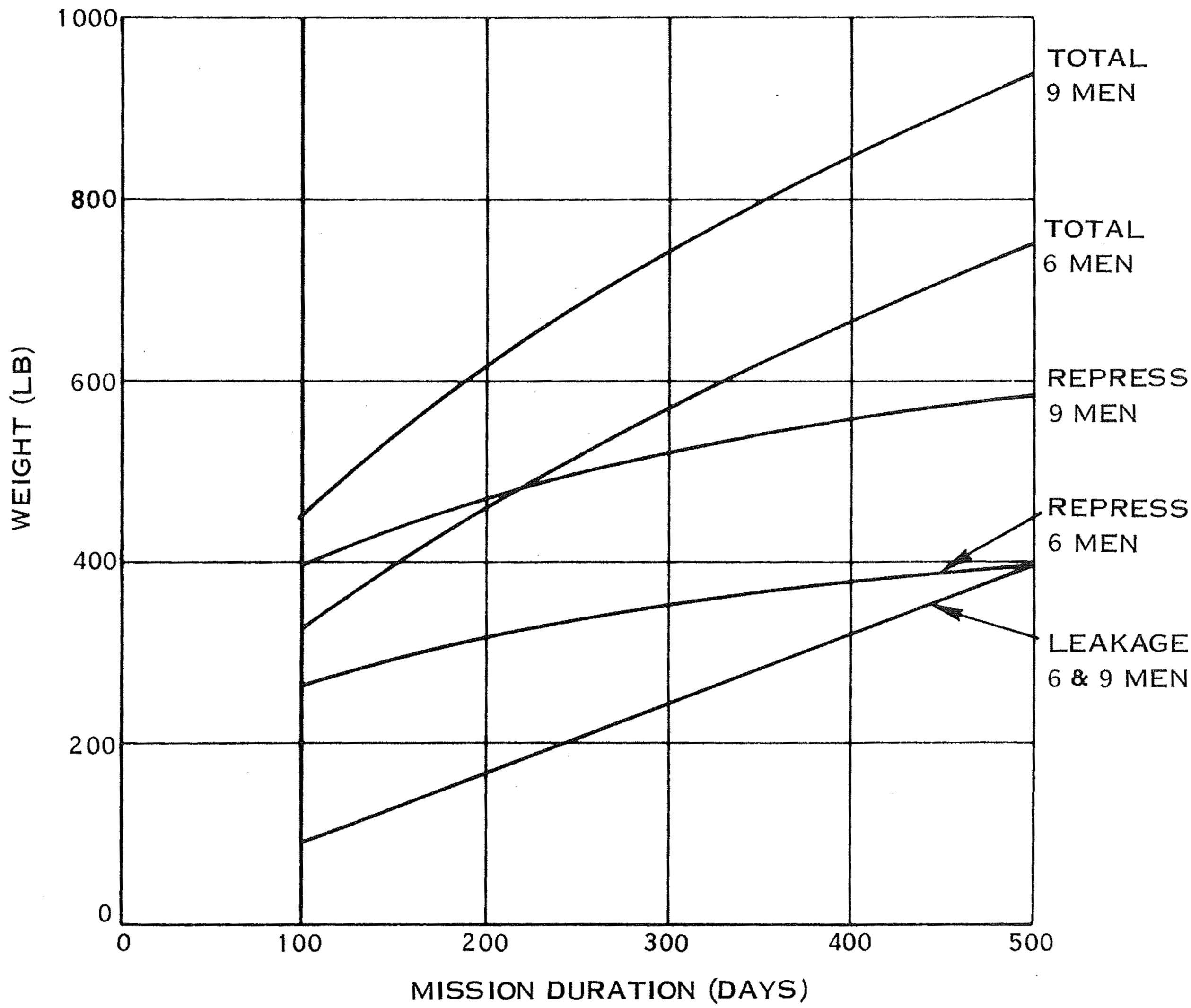

Figure 20. O_2/N_2 Storage - High Pressure Nitrogen - Filament Wound.

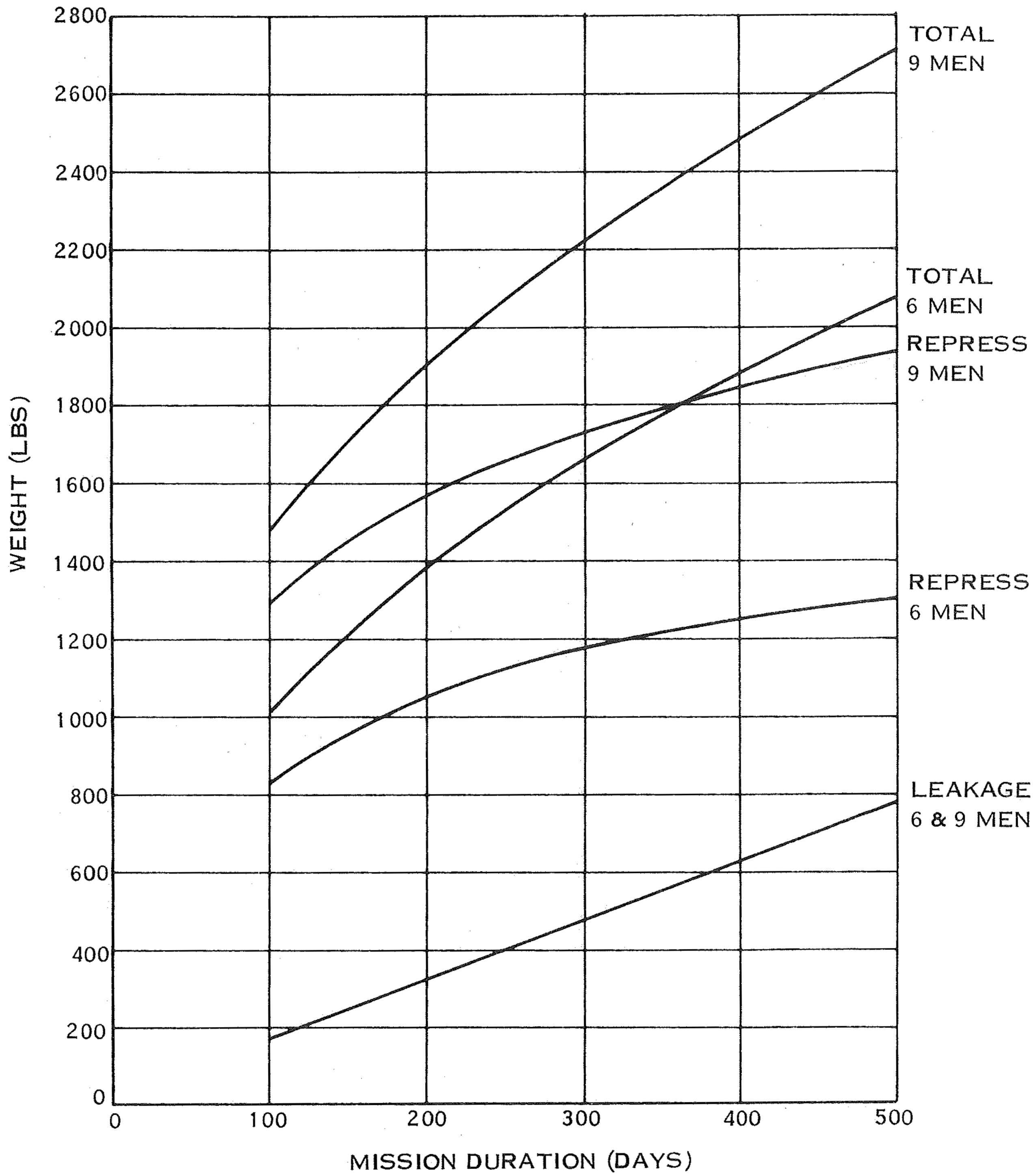

Figure 21. O_2/N_2 Storage - Chlorate Candles for O_2.

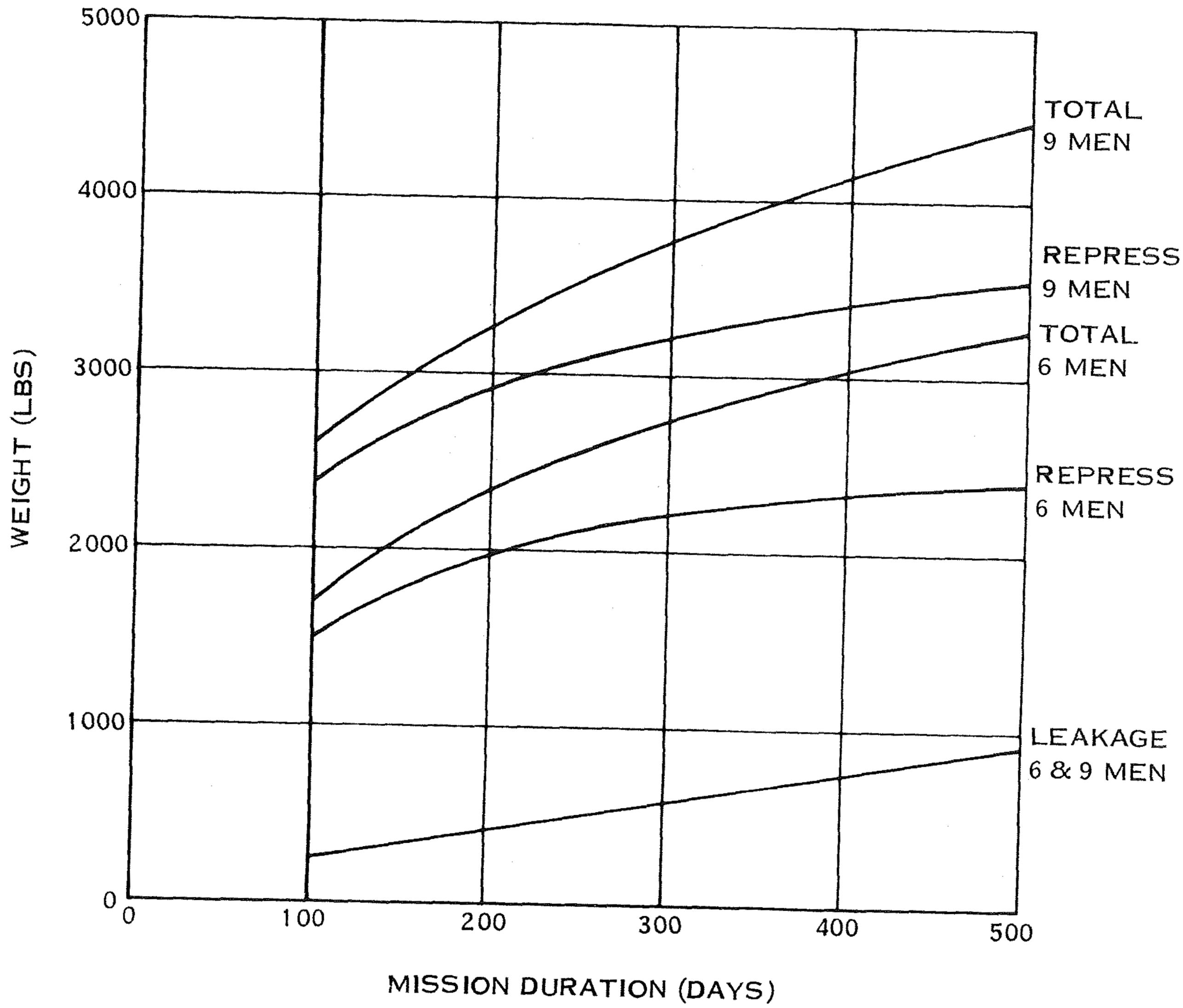

Figure 22. O_2/N_2 Storage - Hydrogen Peroxide.

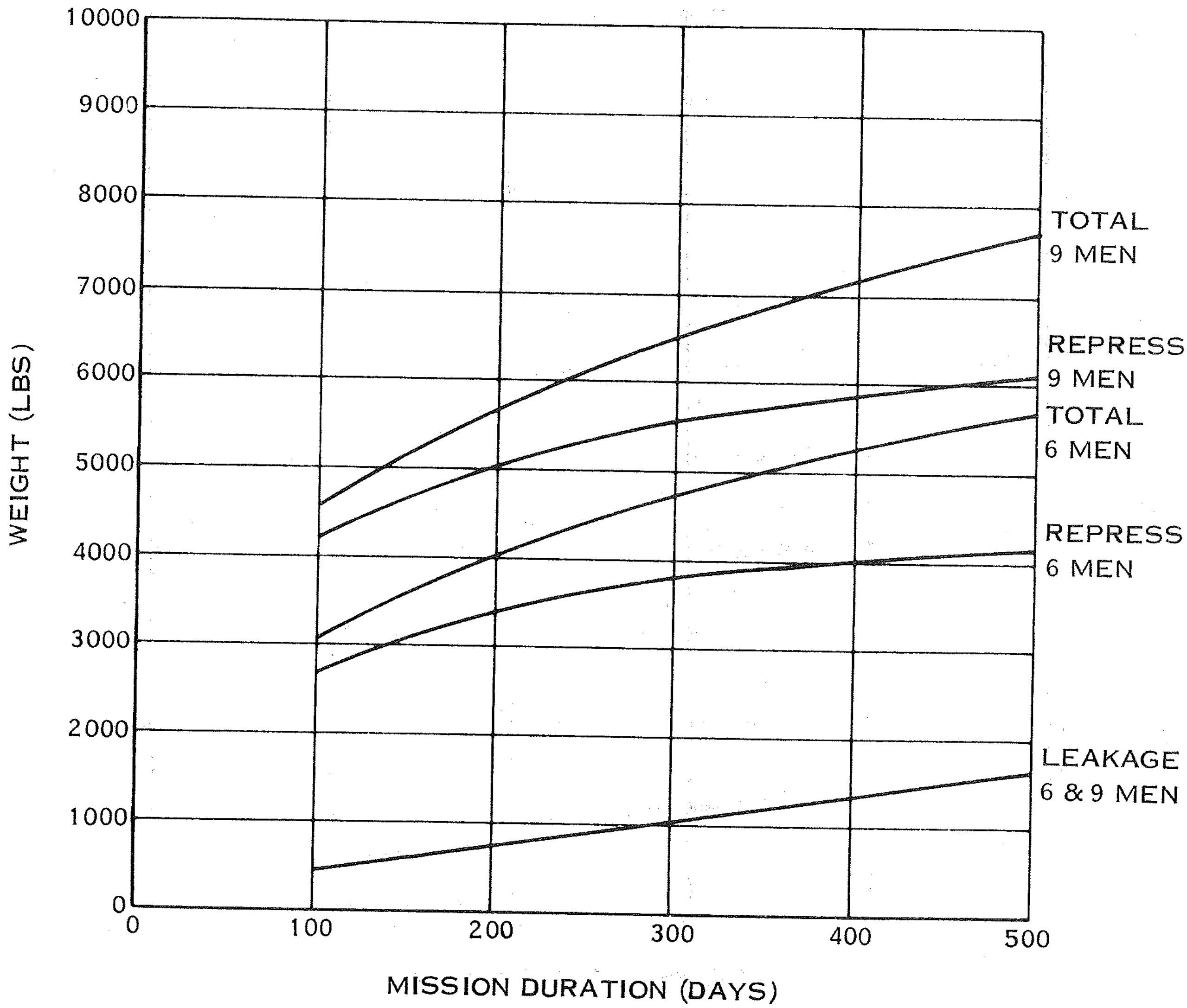

Figure 23. O_2/N_2 Storage - Hydrazine/Nitrogen Tetraoxide.

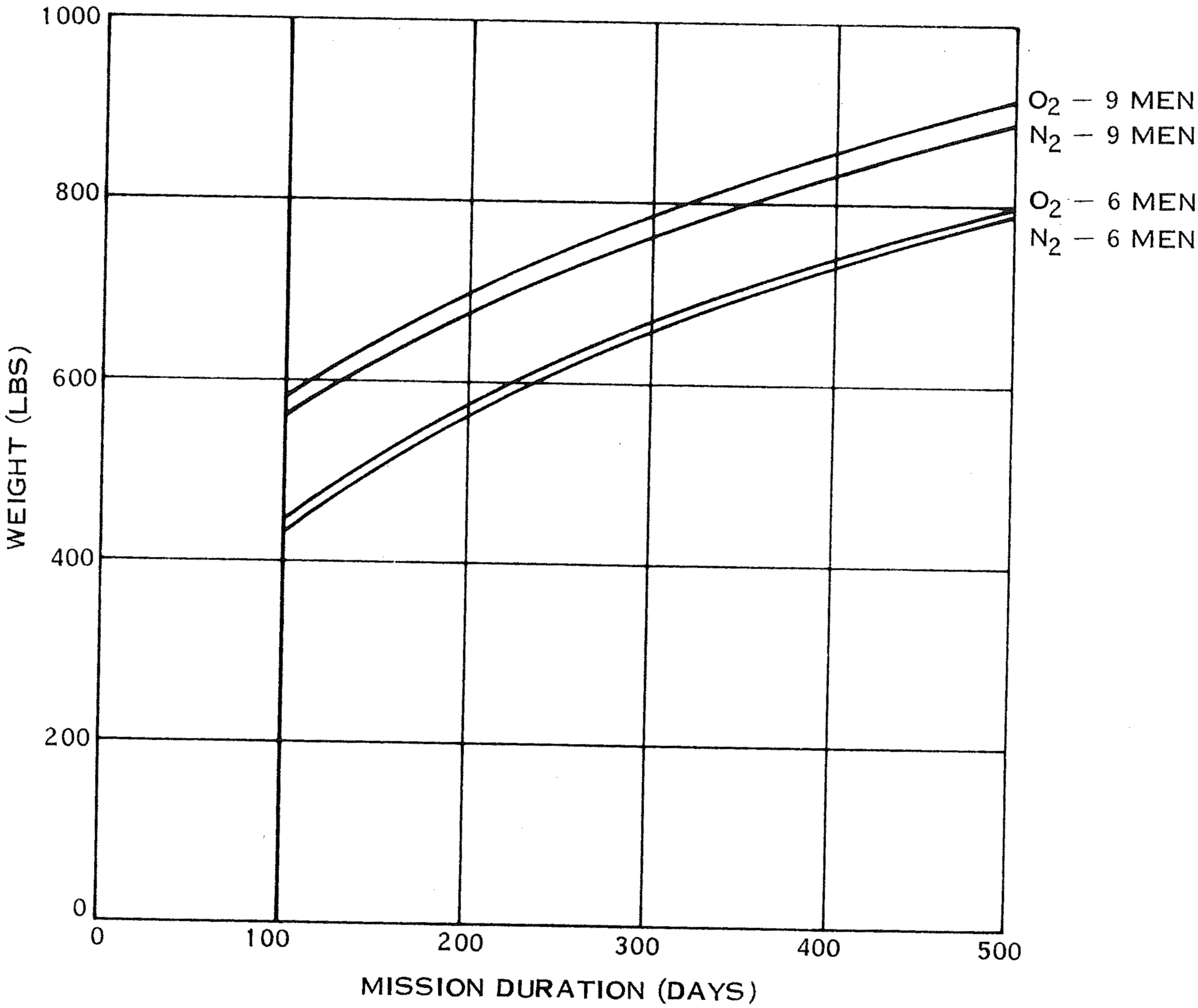

Figure 24. O_2/N_2 Storage Subcritical Cryogenic.

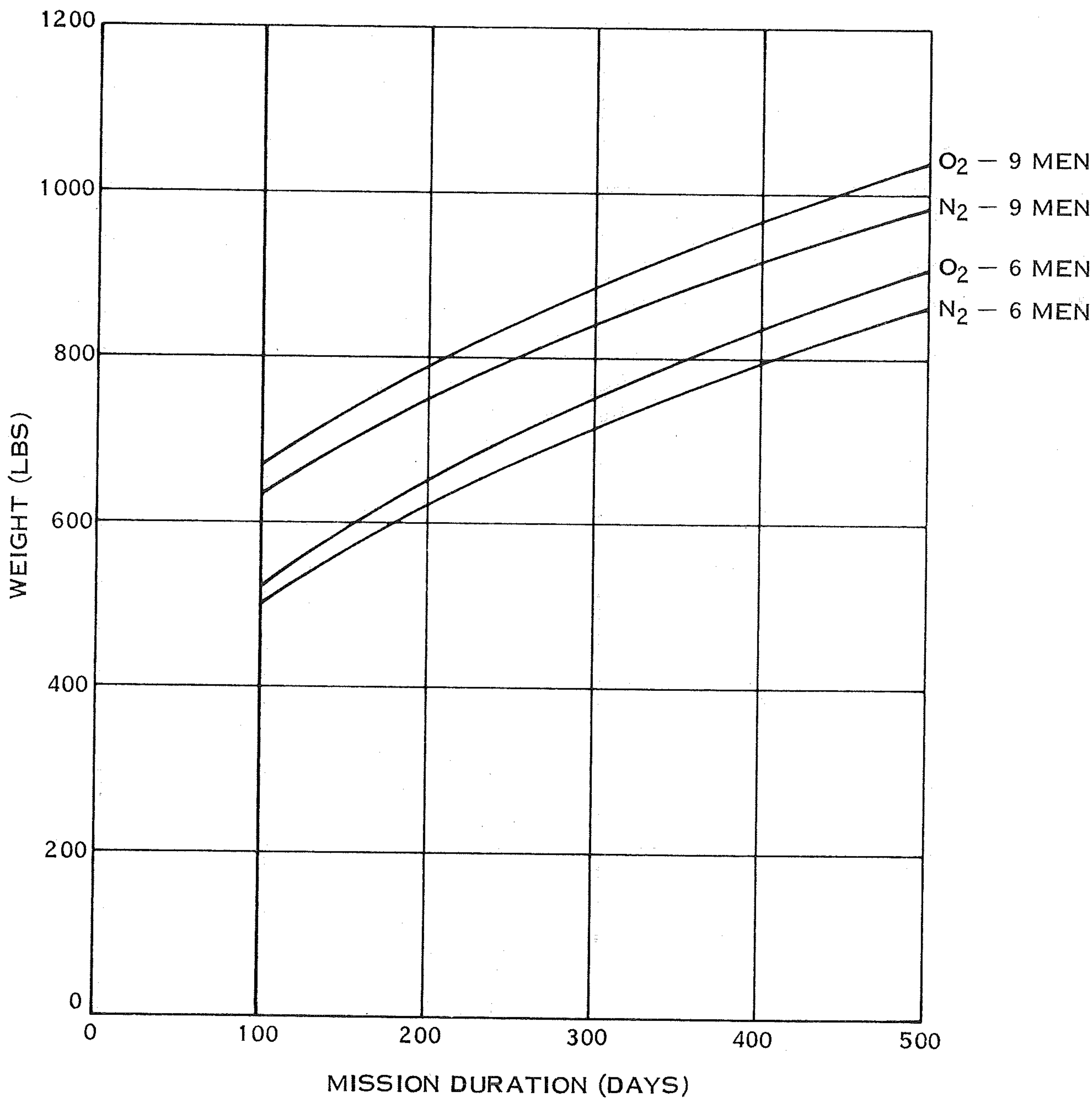

Figure 25. O_2/N_2 Storage Supercritical Cryogenic.

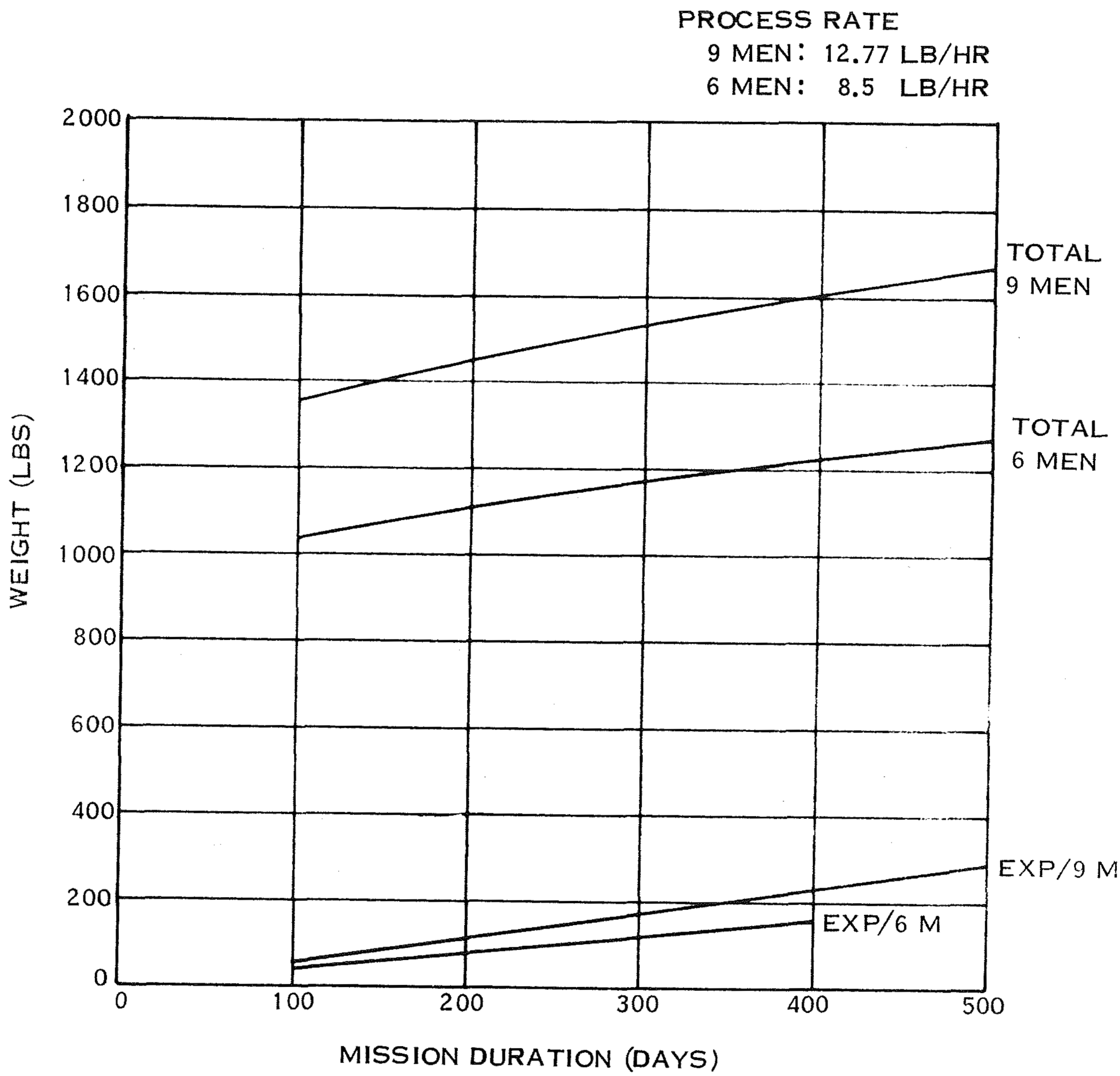

Figure 26. Water Reclamation - Vapor Compression.

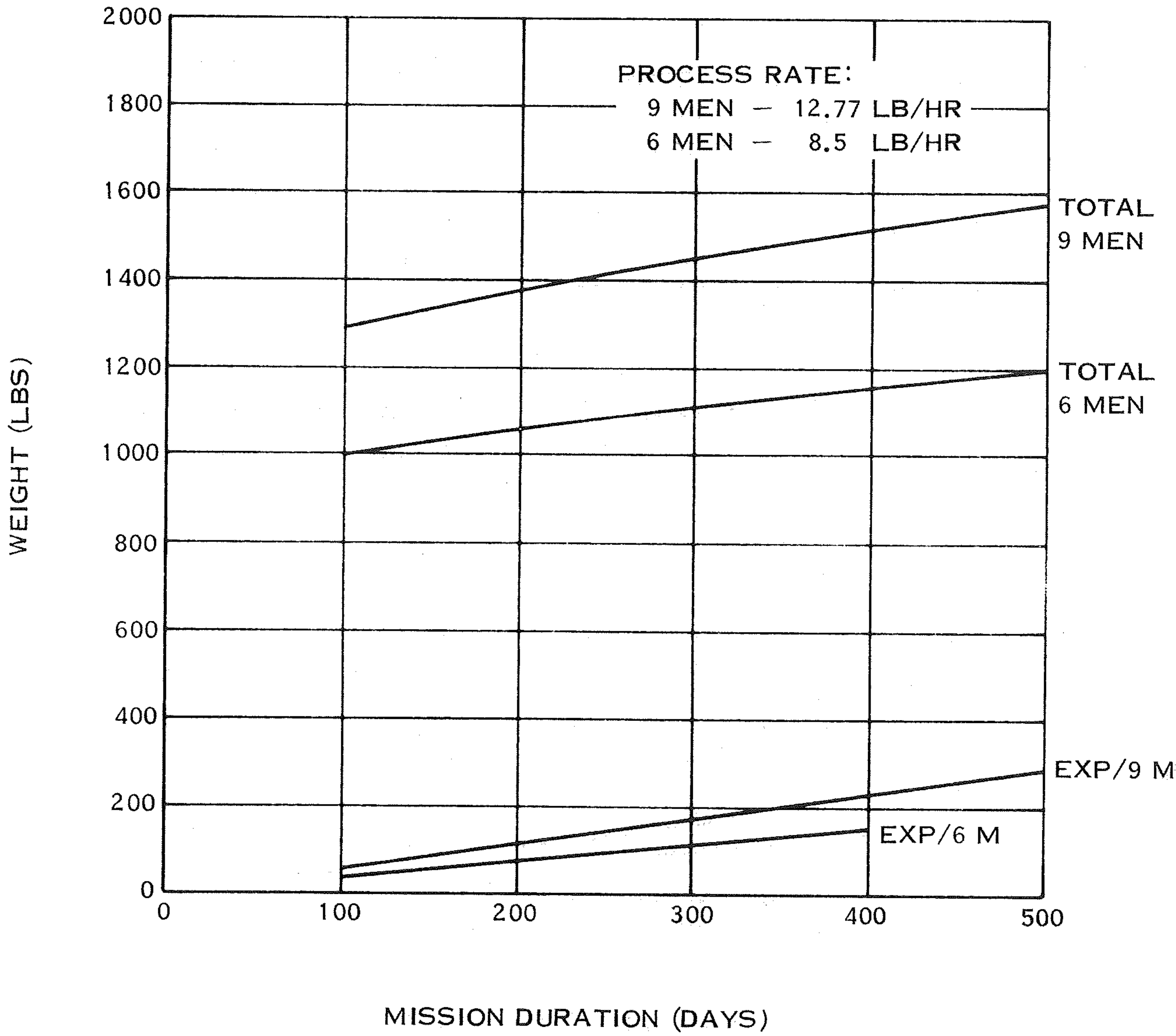

Figure 27. Water Reclamation - Thermoelectric.

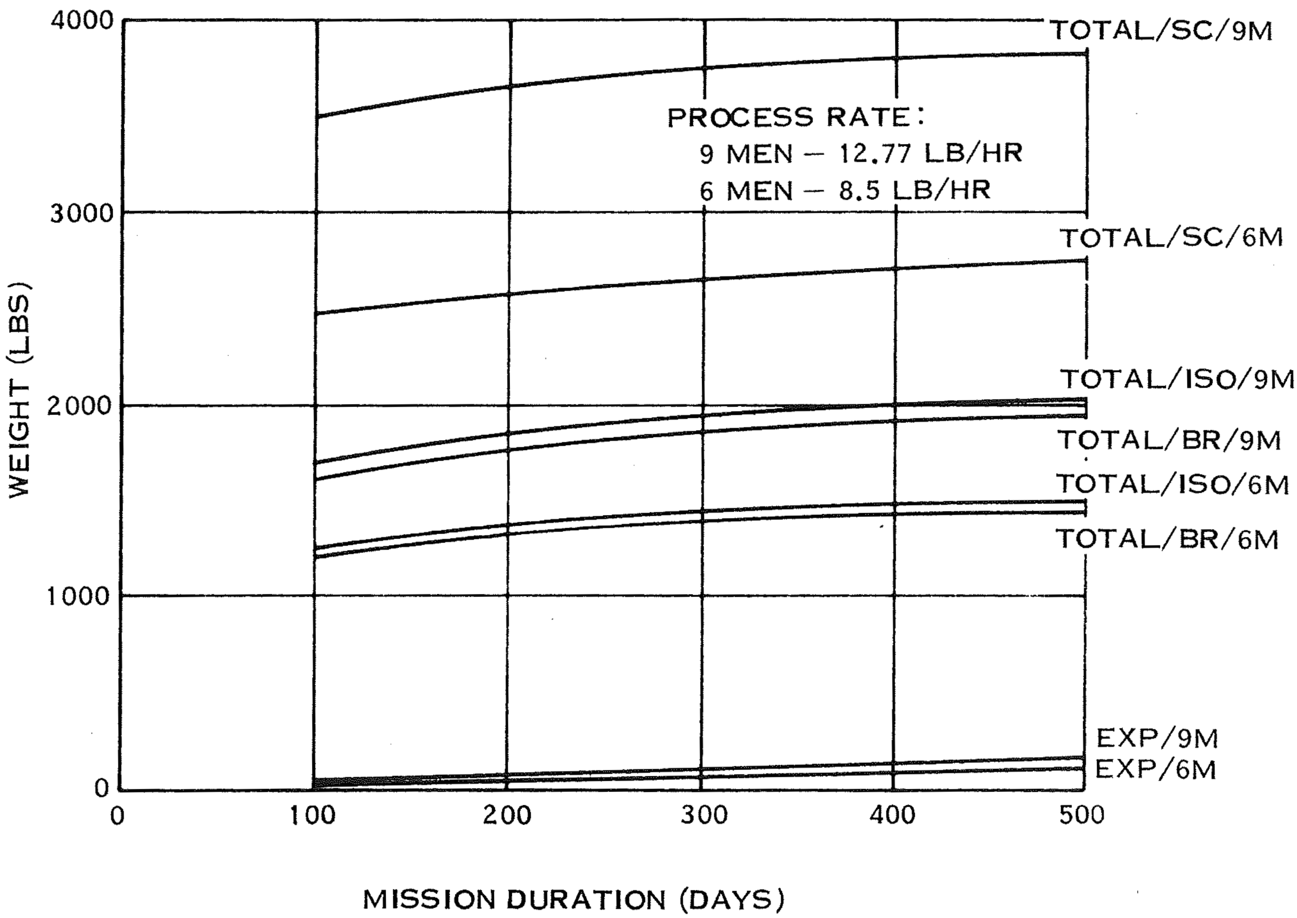

Figure 28. Water Reclamation - Vacuum Distillation/Pyrolysis and Flash Evaporation/Pyrolysis.

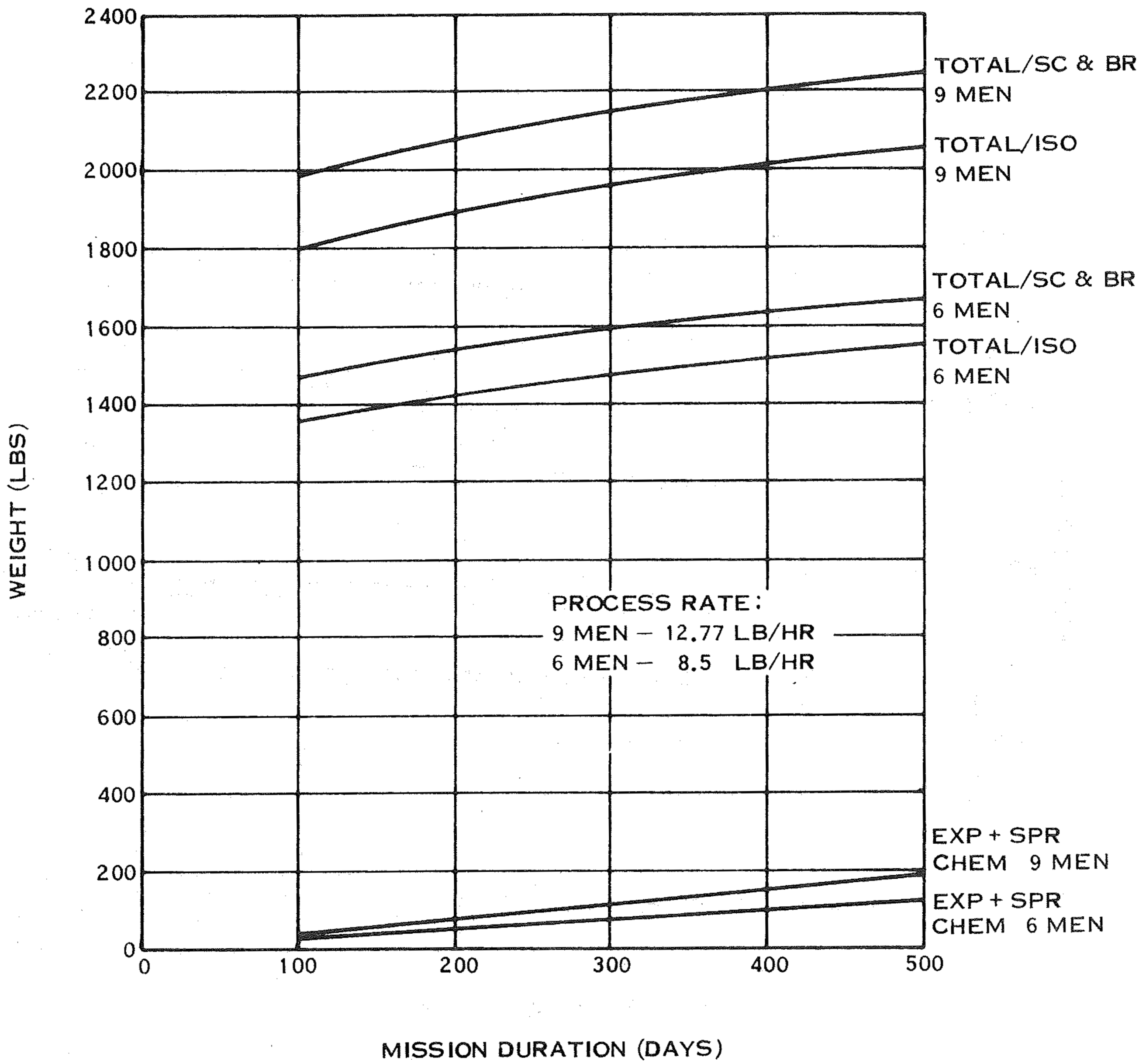

Figure 29. Water Reclamation - Flash Evaporation/Compression.

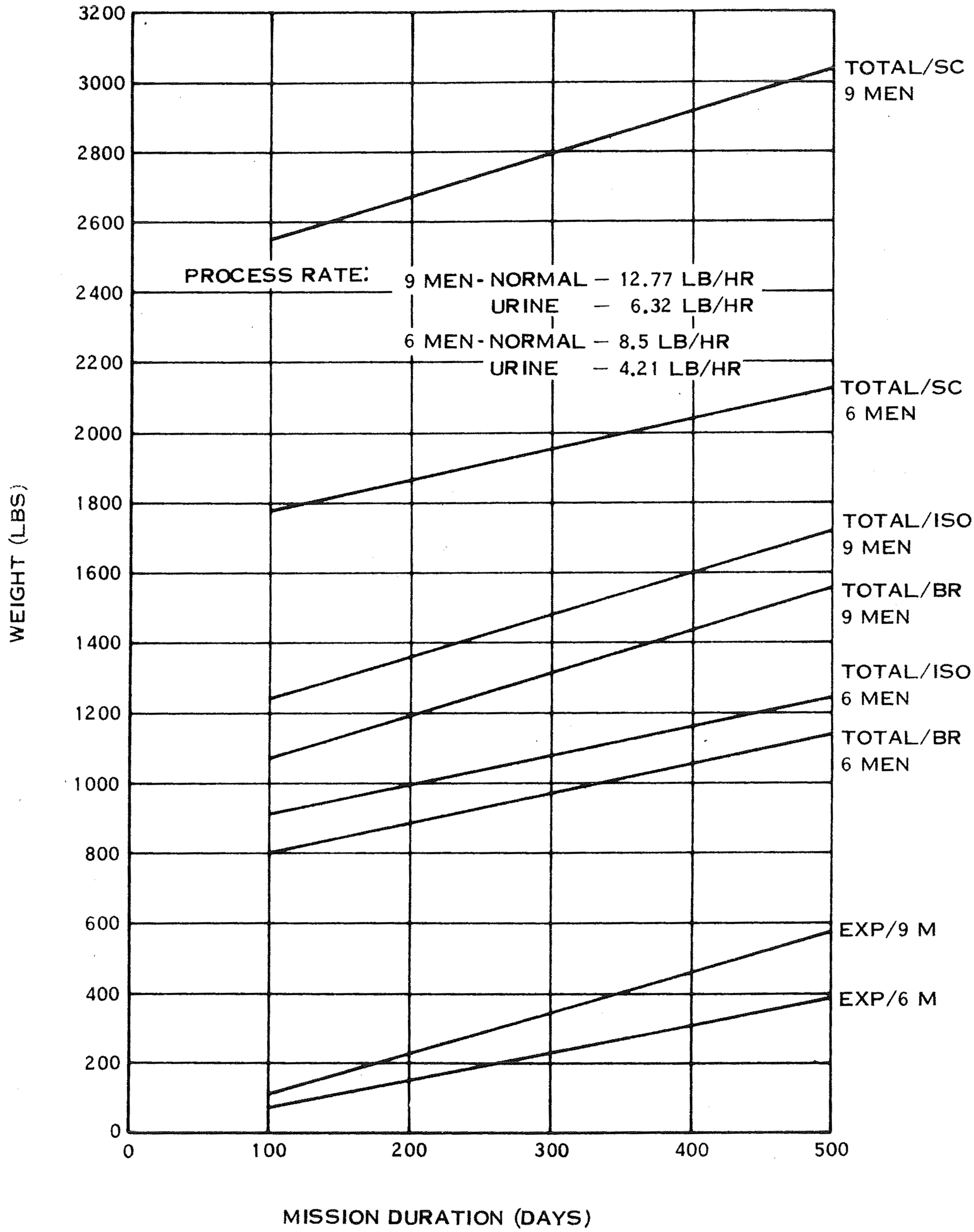

Figure 30. Water Reclamation - Closed Cycle Air Evaporation.

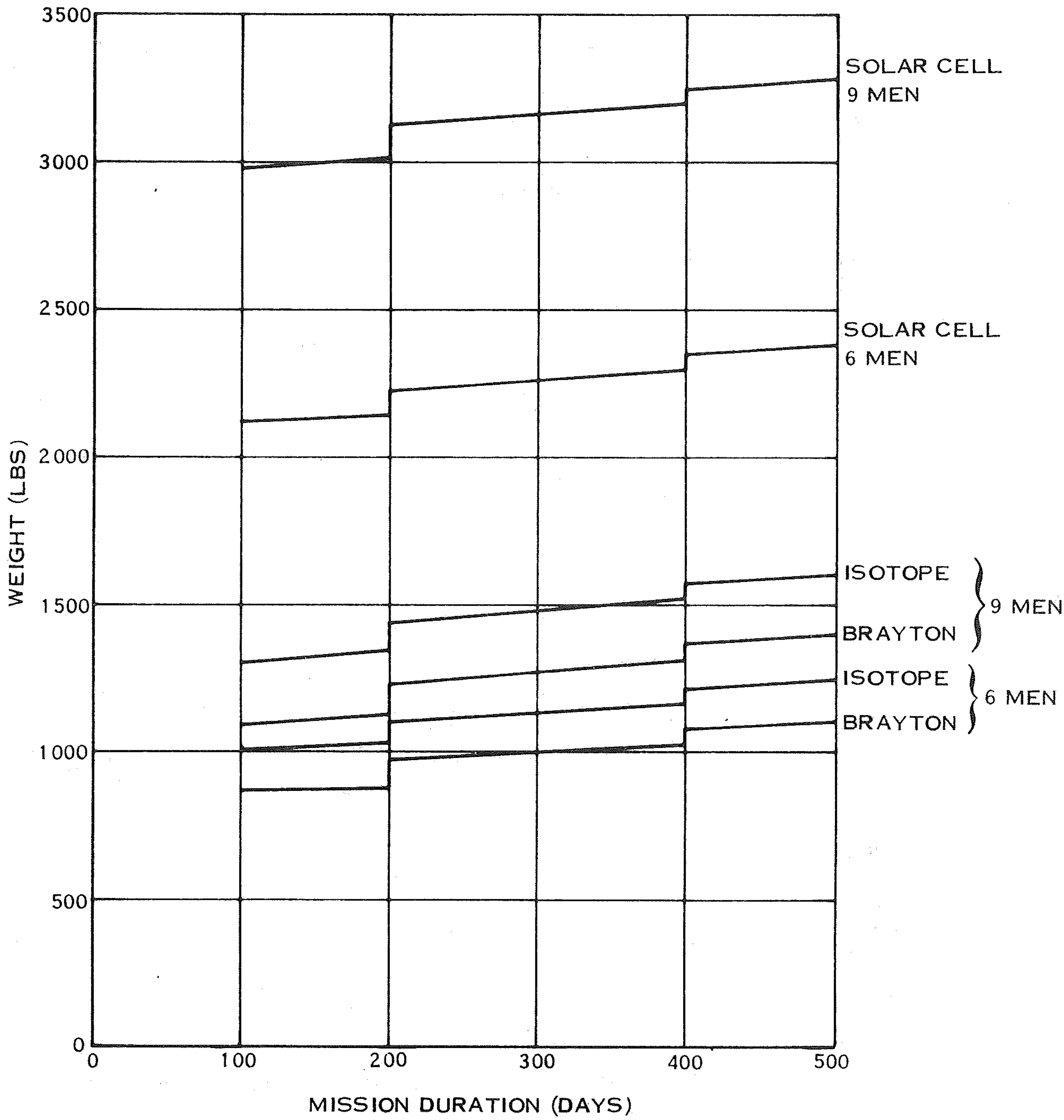

Figure 31. Water Reclamation - Vapor Diffusion.

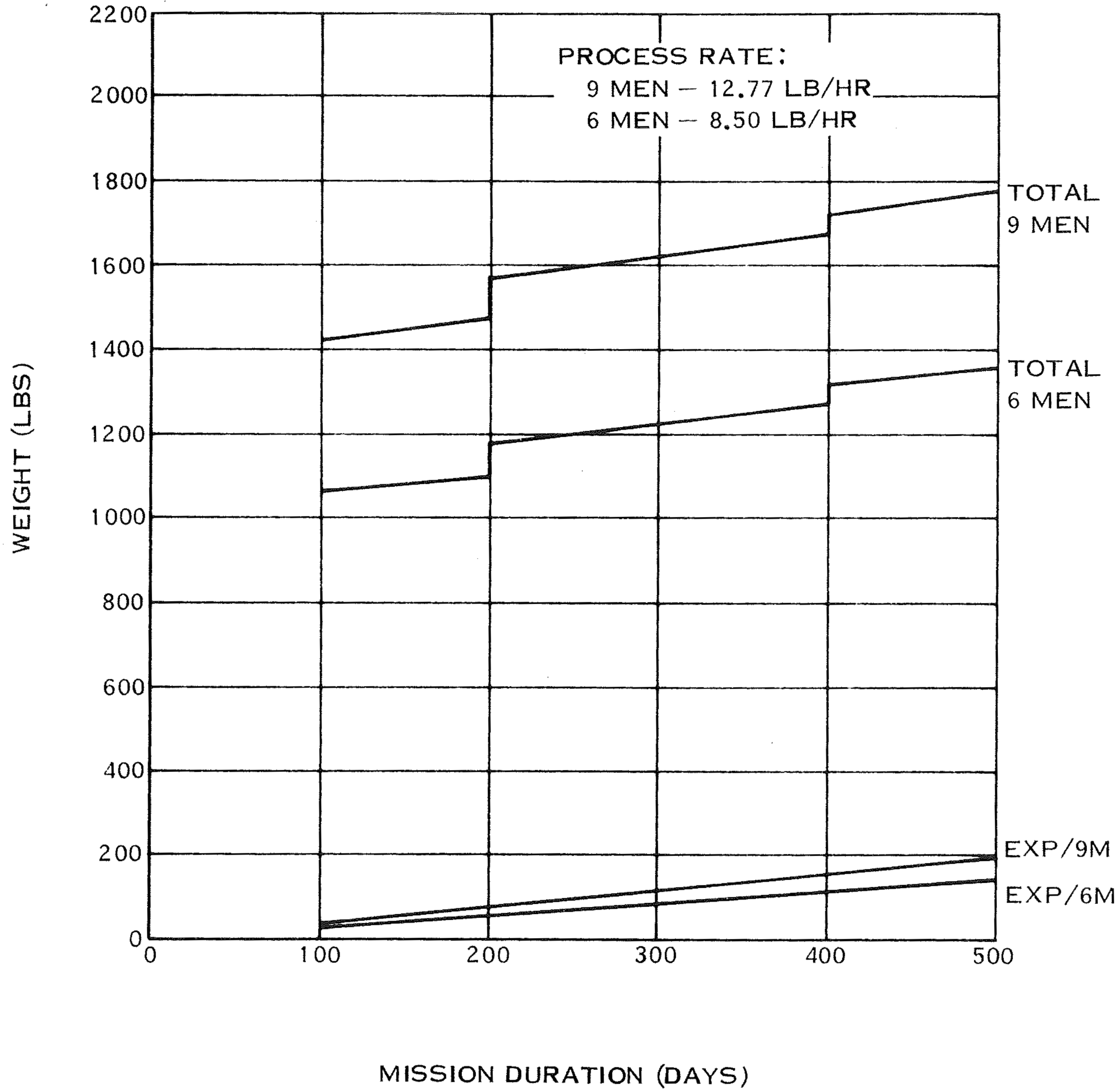

Figure 32. Water Reclamation - Vapor Diffusion/ Compression.

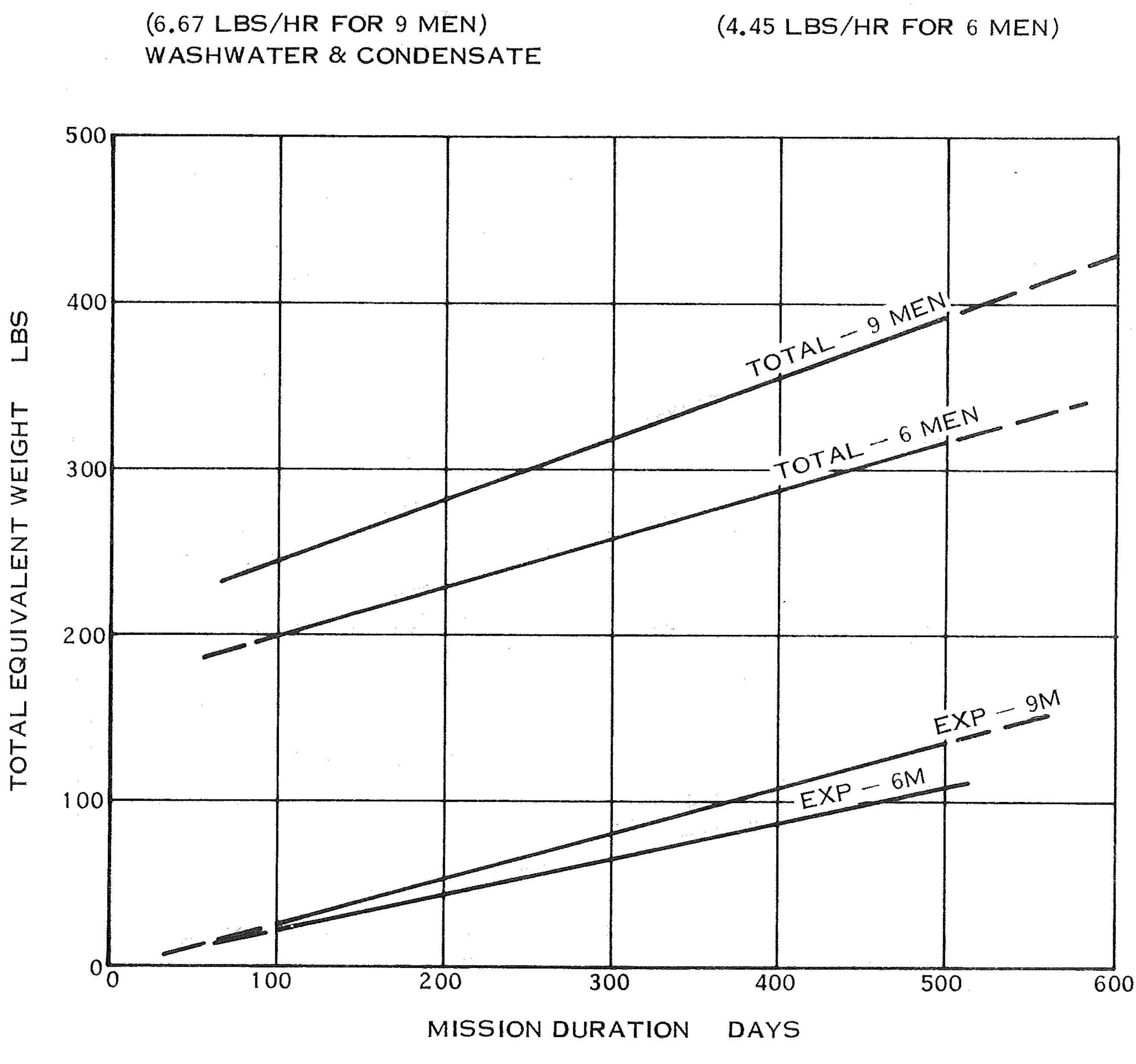

Figure 33. Water Reclamation - Reverse Osmosis.

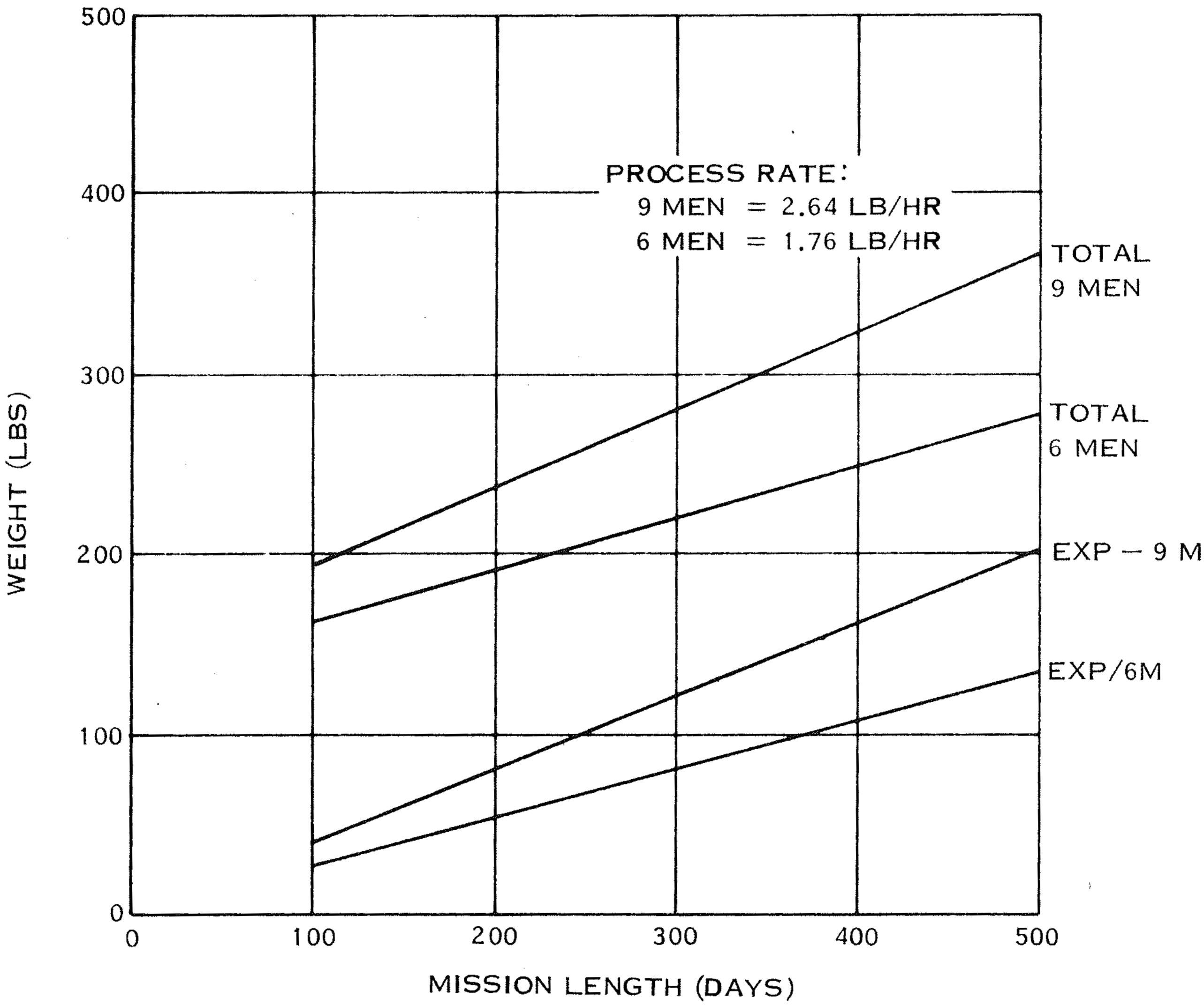

Figure 34. Water Reclamation - Multifiltration.

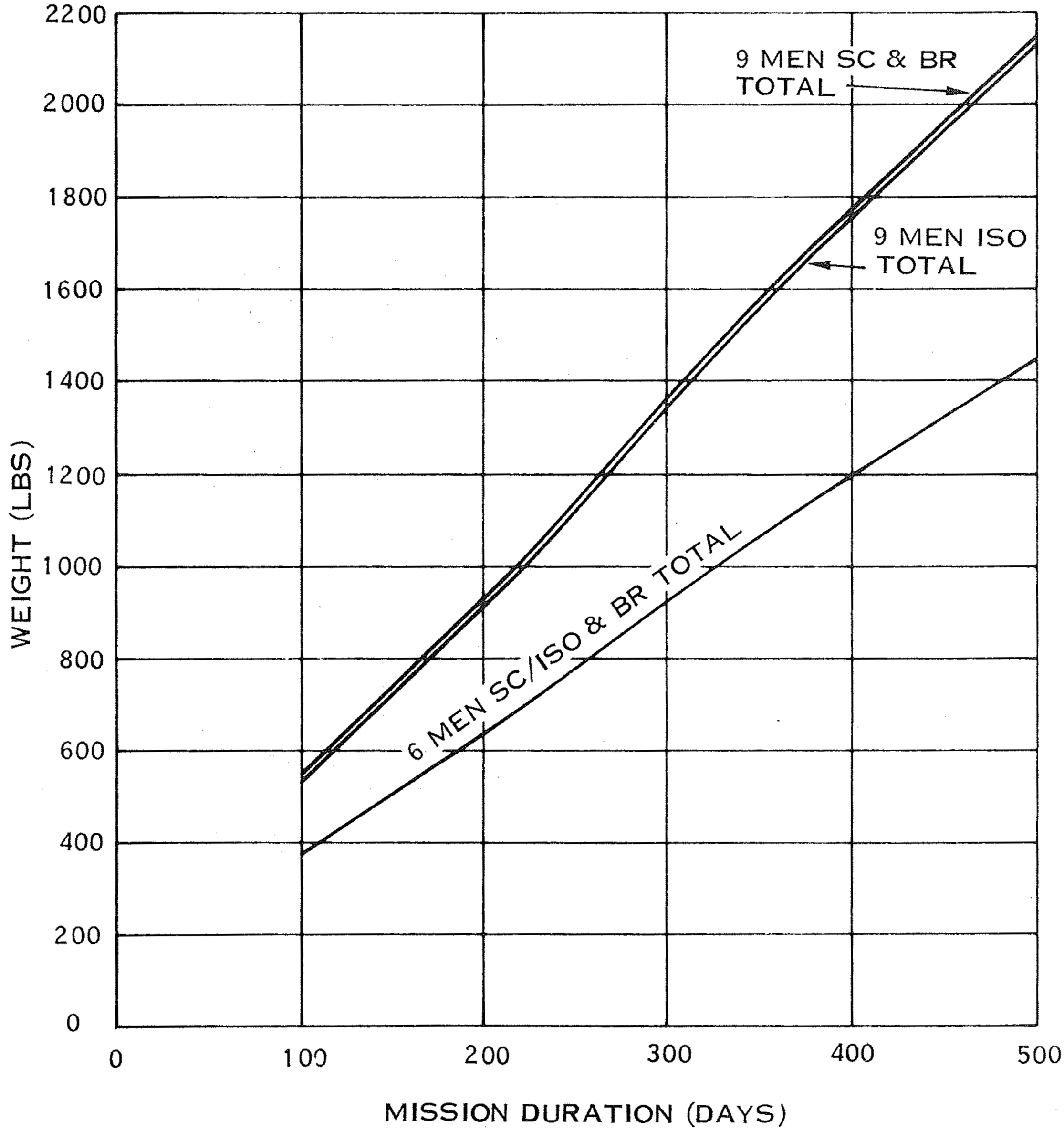

Figure 35. Contaminant Control - Nonregenerable Charcoal/Catalytic Oxidation.

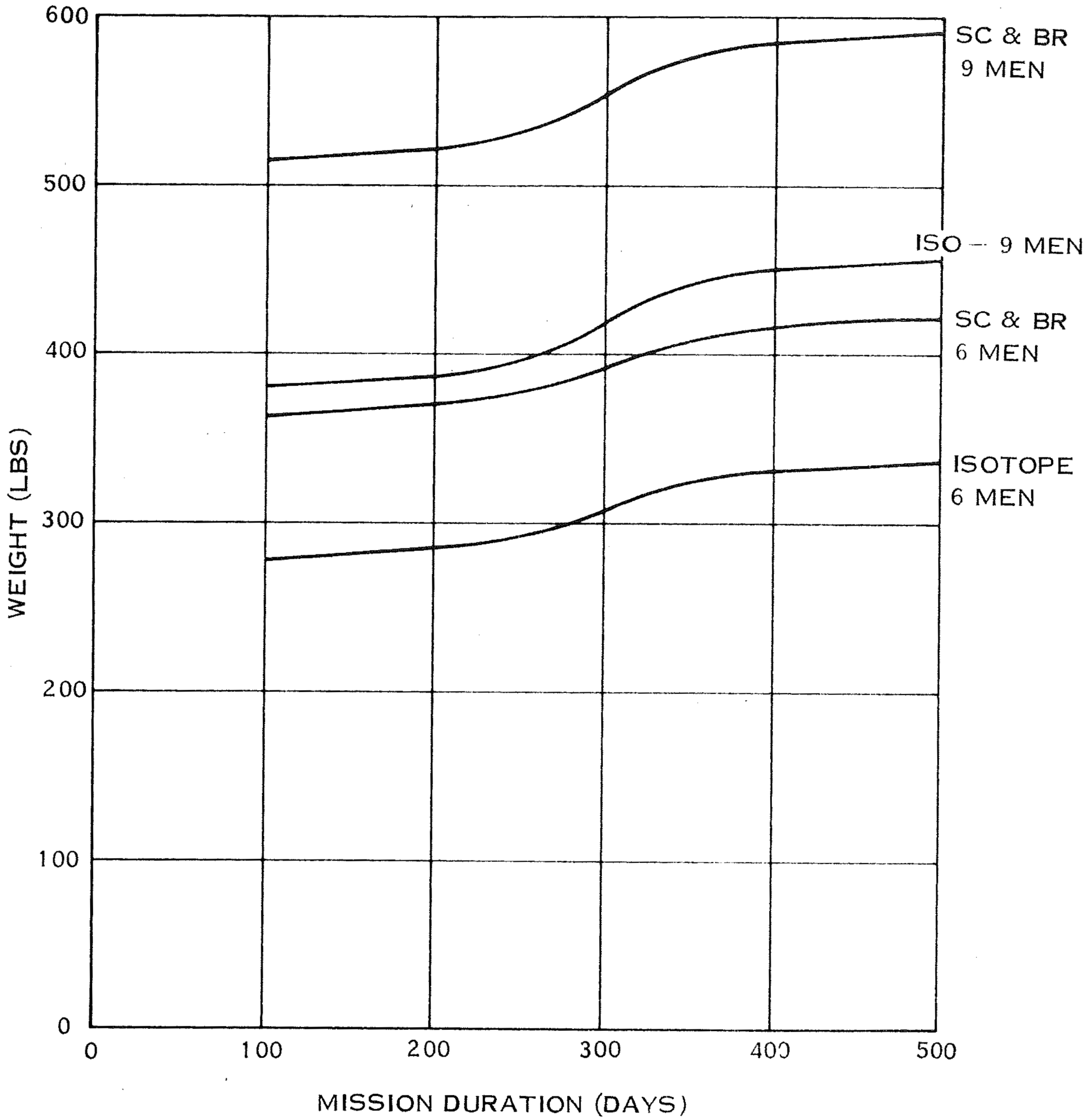

Figure 36. Contaminant Control - Regenerable Charcoal/Catalytic Oxidation.

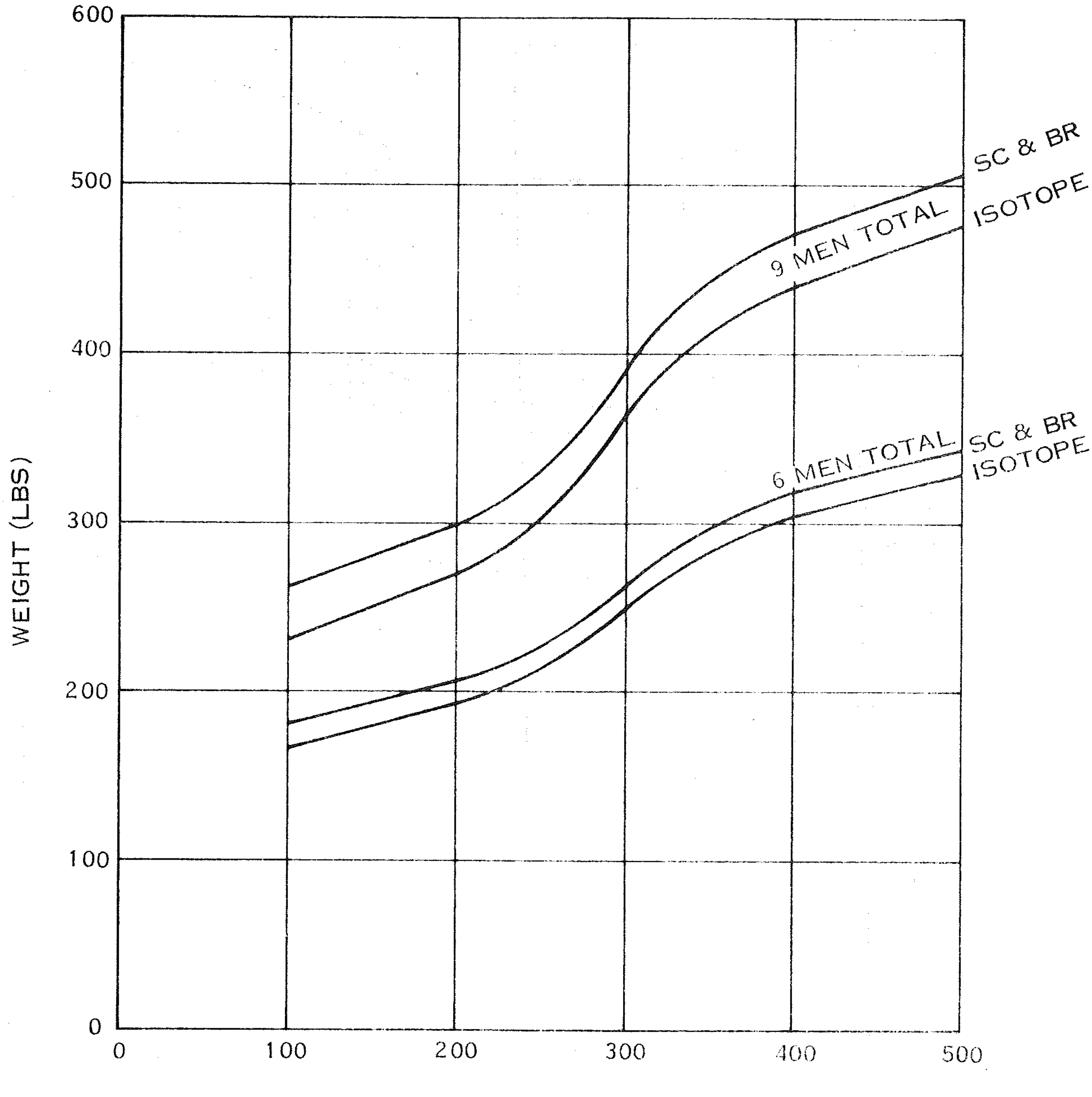

Figure 37. Contaminant Control - Catalytic Oxidation/Sorption.

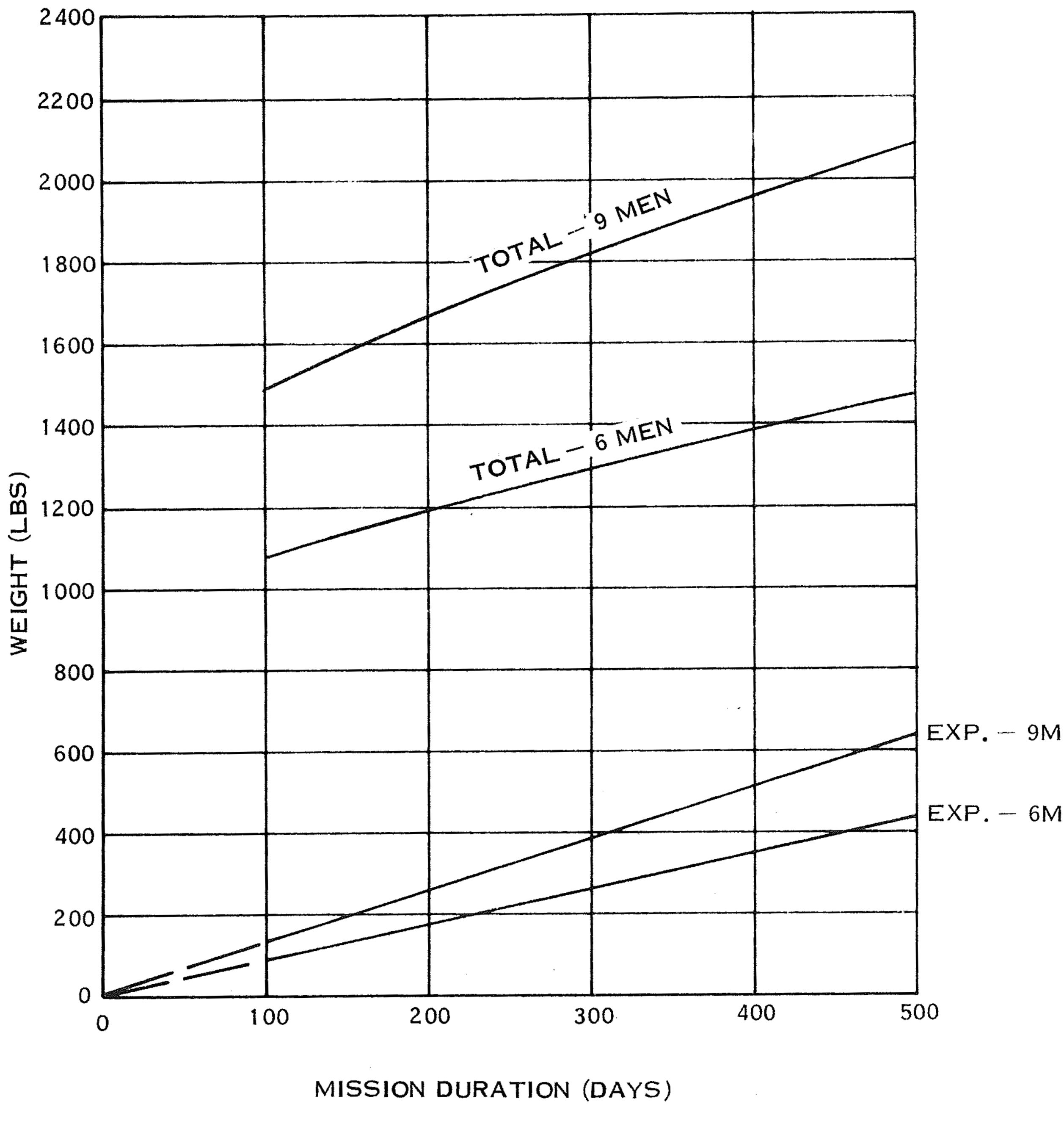

Figure 38. CO_2 Reduction - Solid Electrolyte.

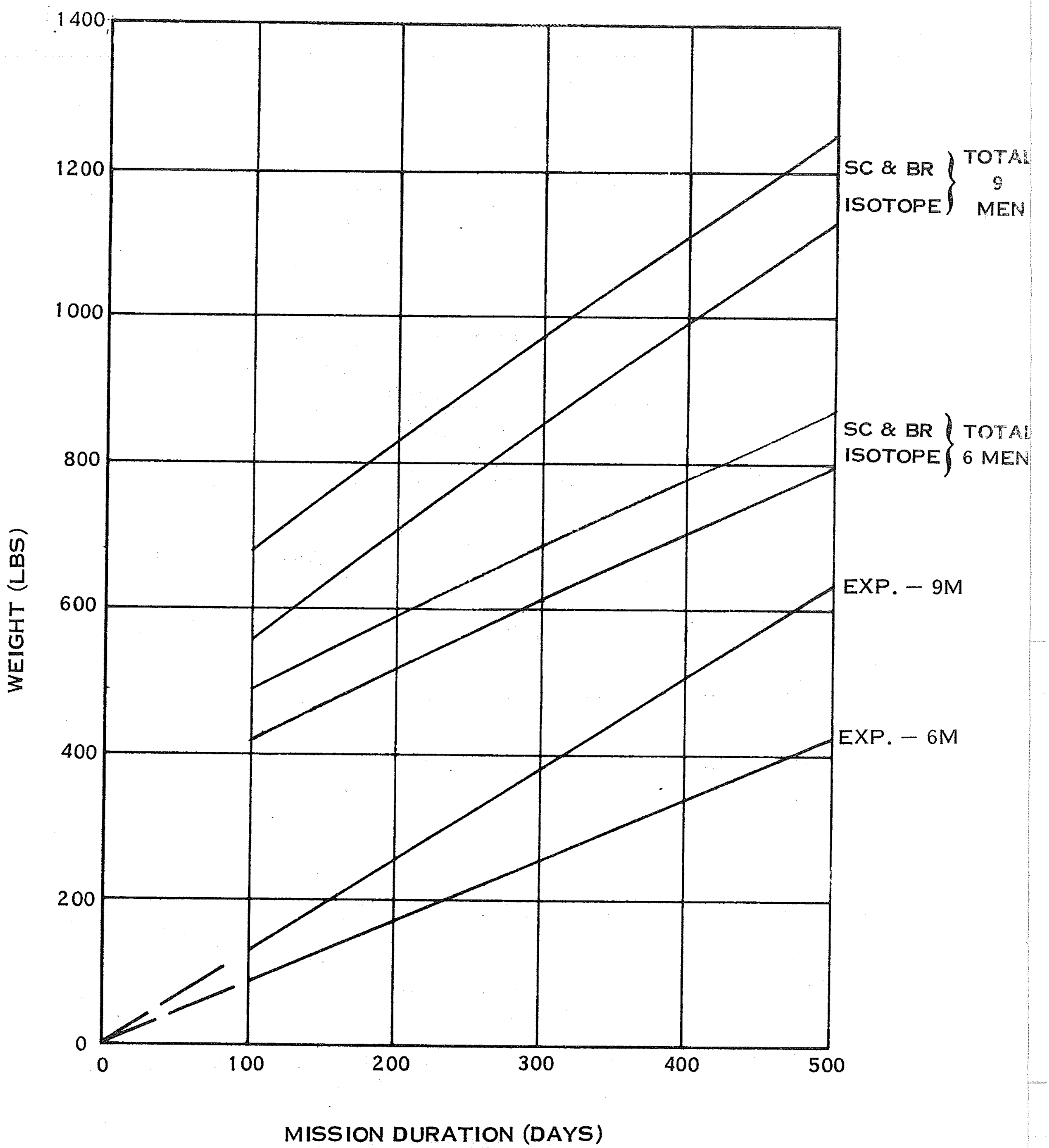

Figure 39. CO_2 Reduction - Bosch.

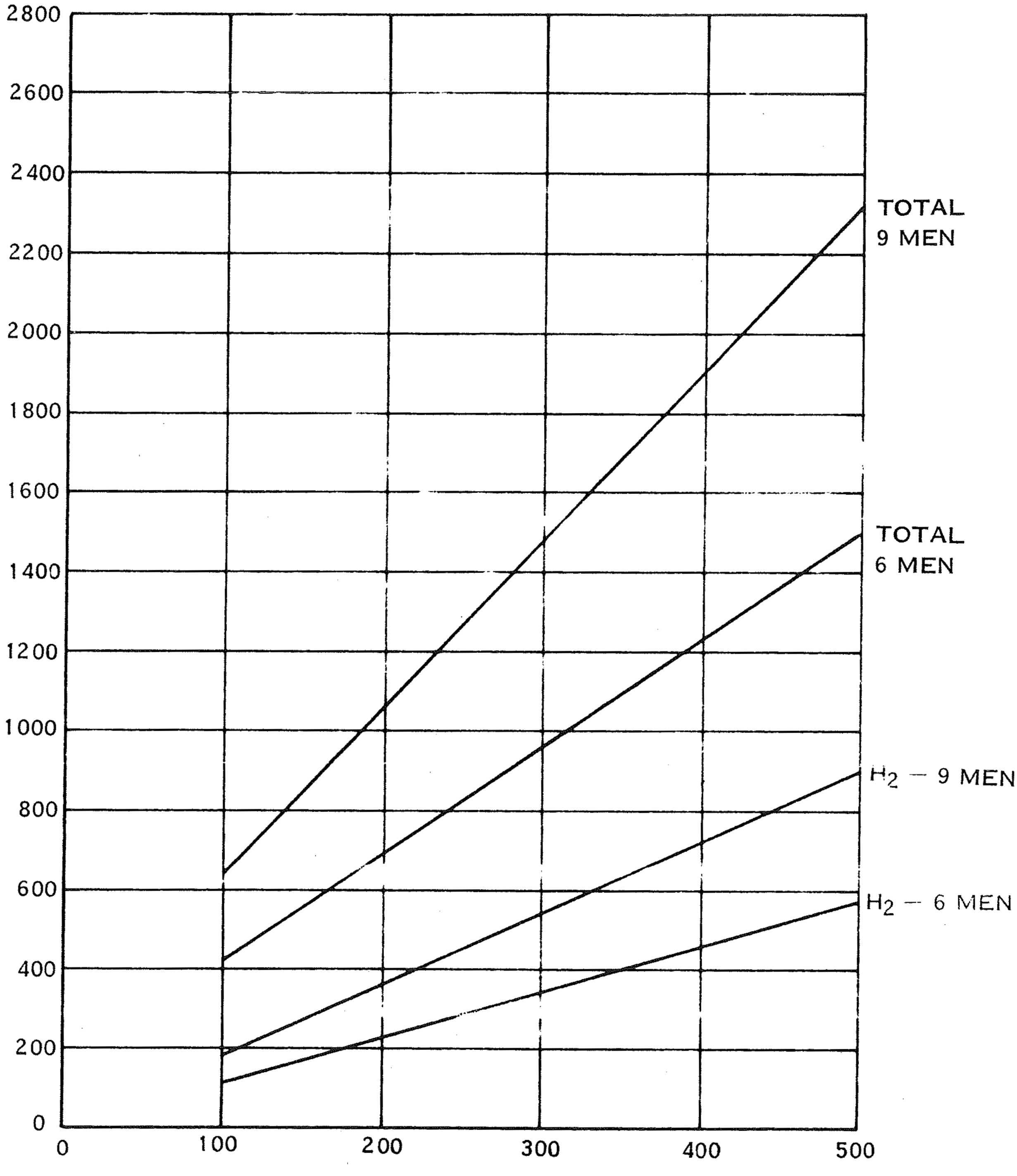

Figure 40. CO_2 Reduction - Sabatier/Methane Dump.

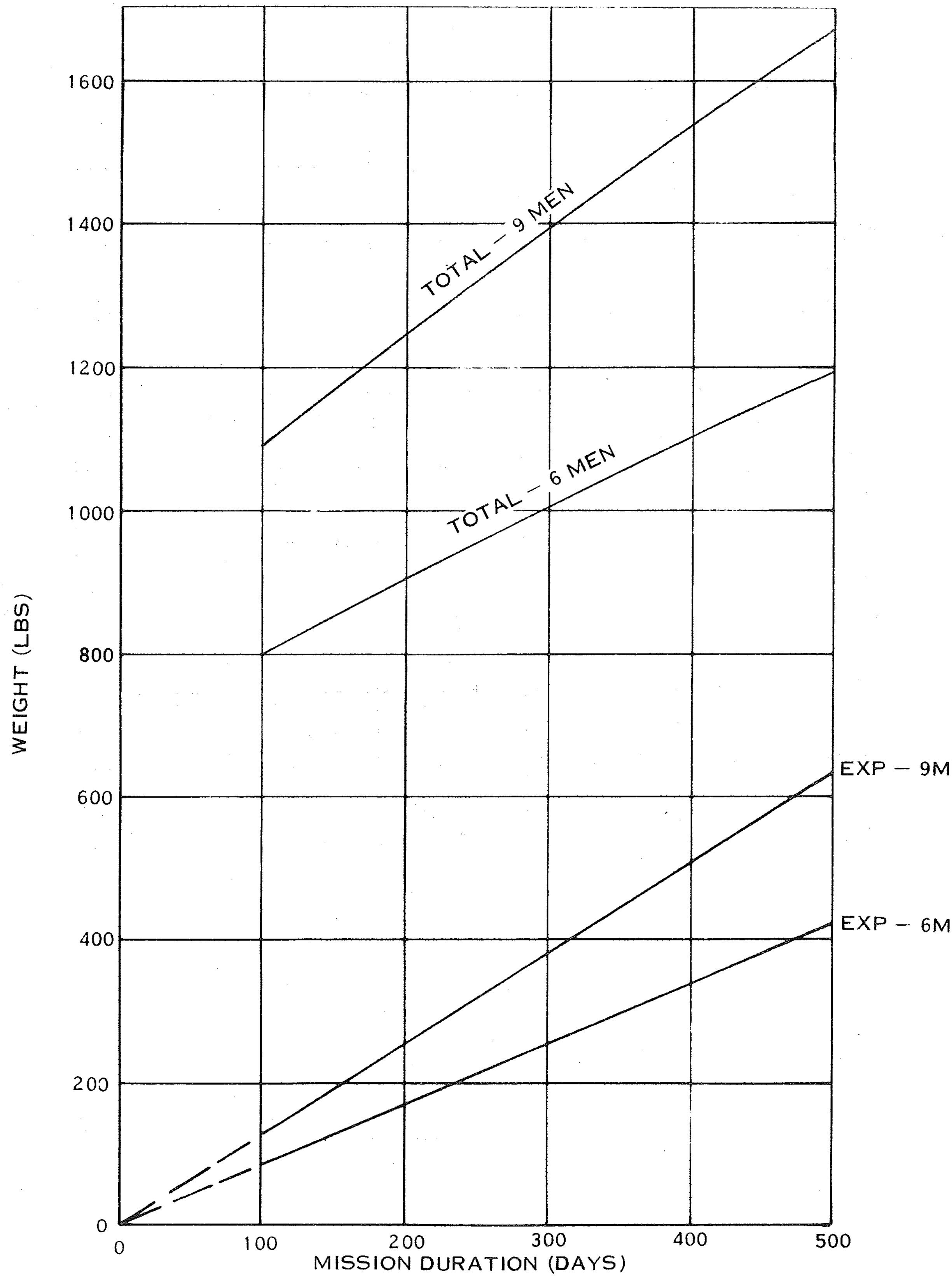

Figure 41. CO_2 Reduction - Sabatier/Methane Cracking.

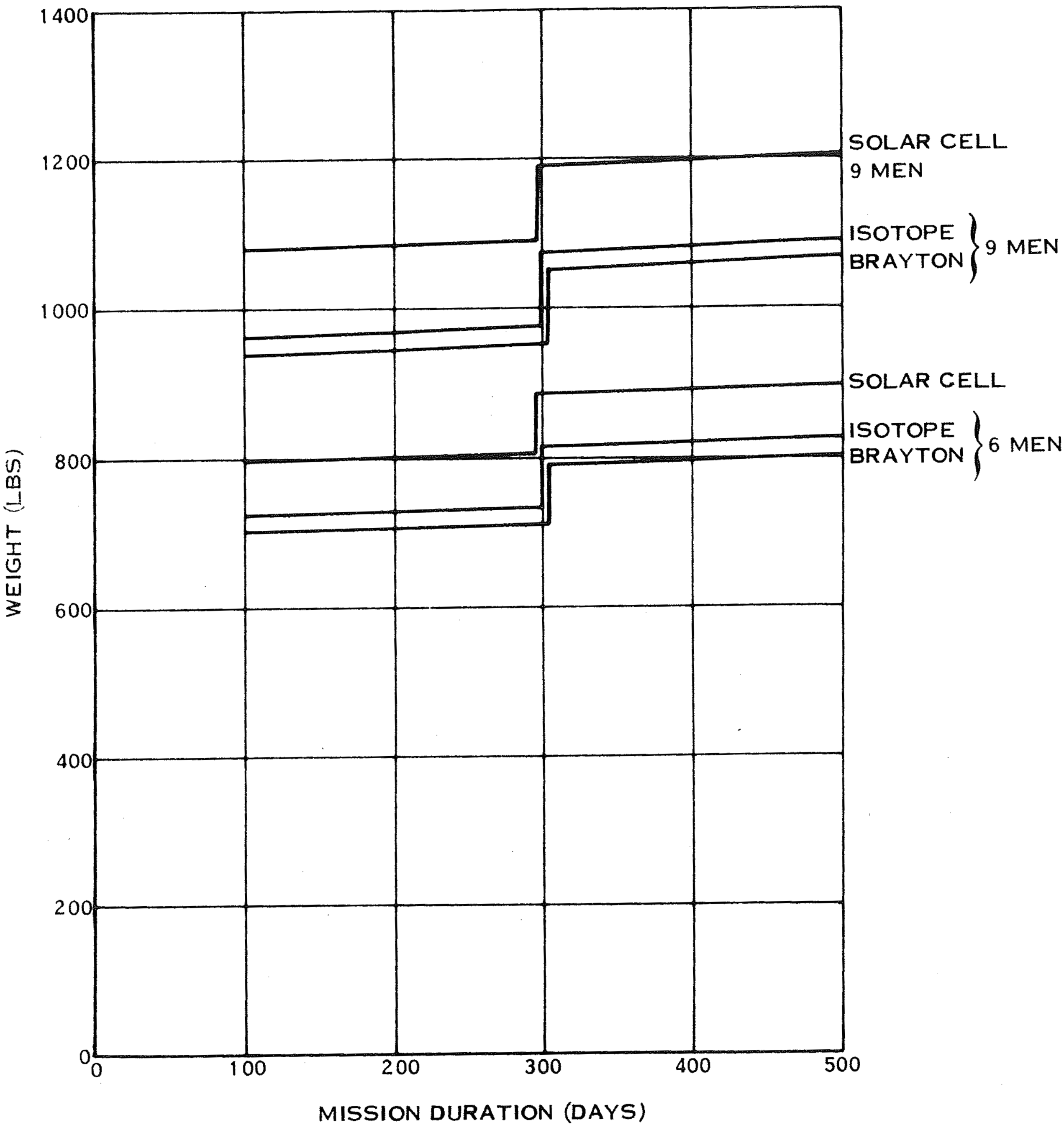

Figure 42. CO_2 Concentration - Molecular Sieve.

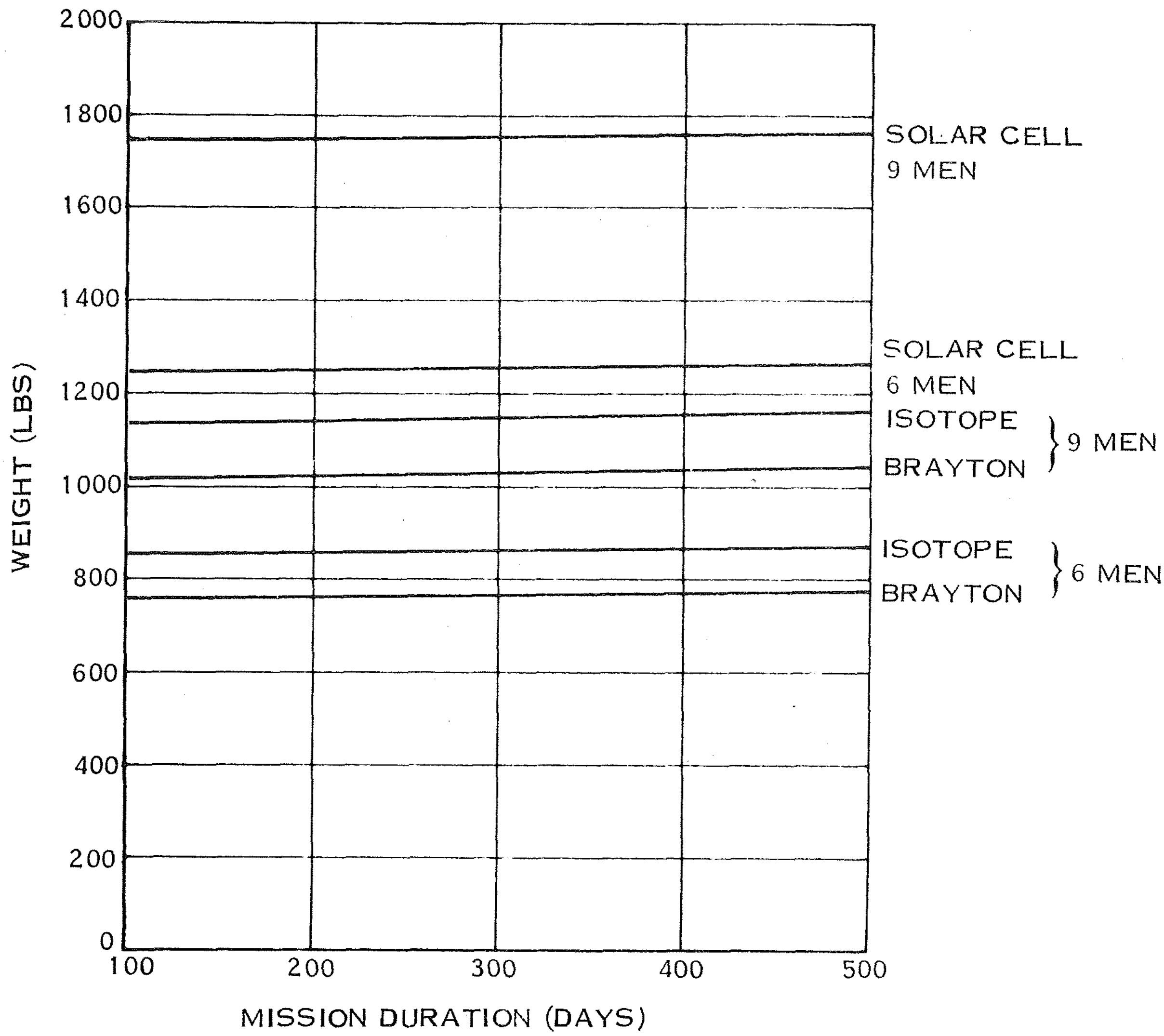

Figure 43. CO_2 Concentration - Solid Amine.

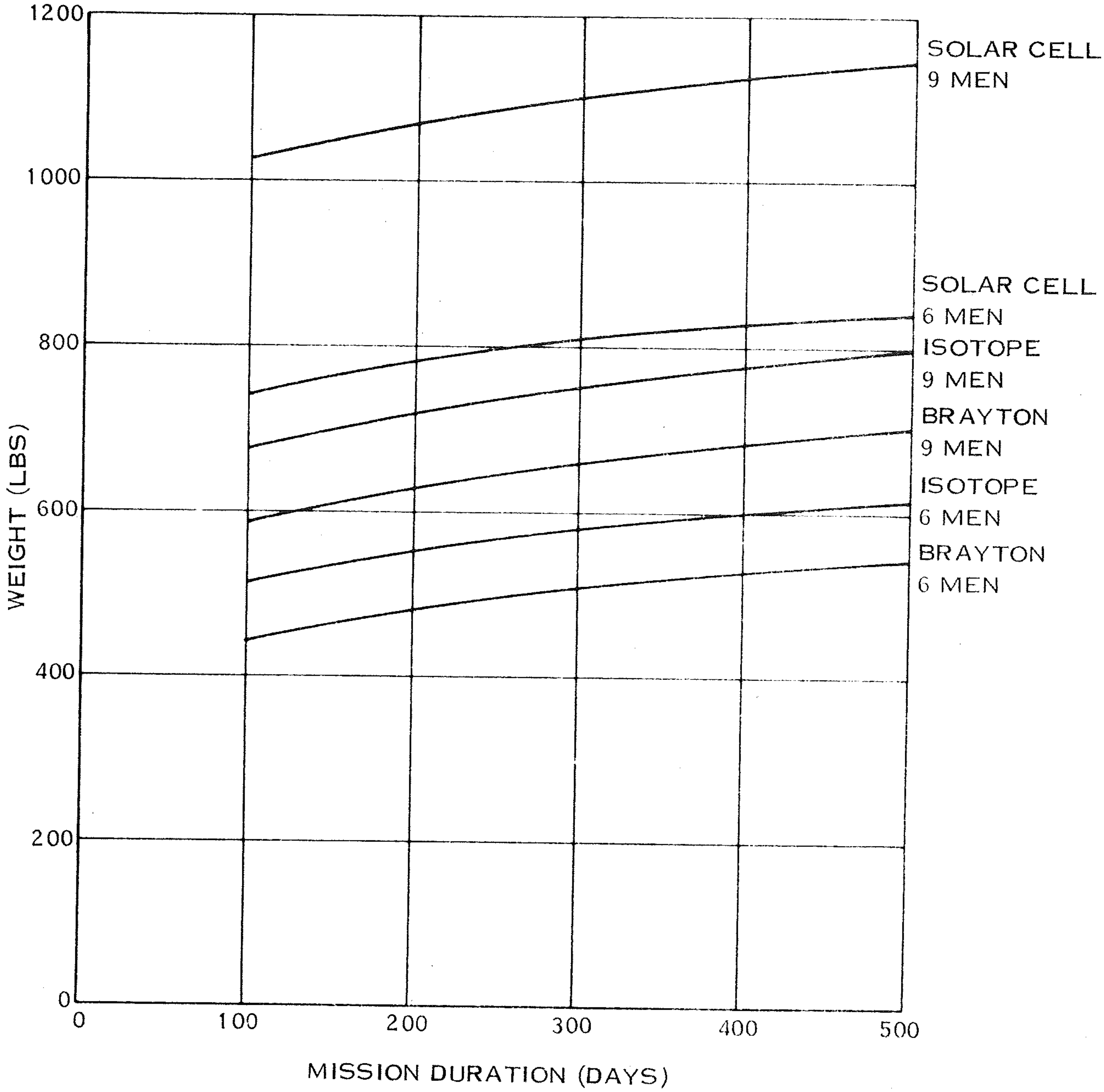

Figure 44. CO_2 Concentration - Steam Desorbed Resin.

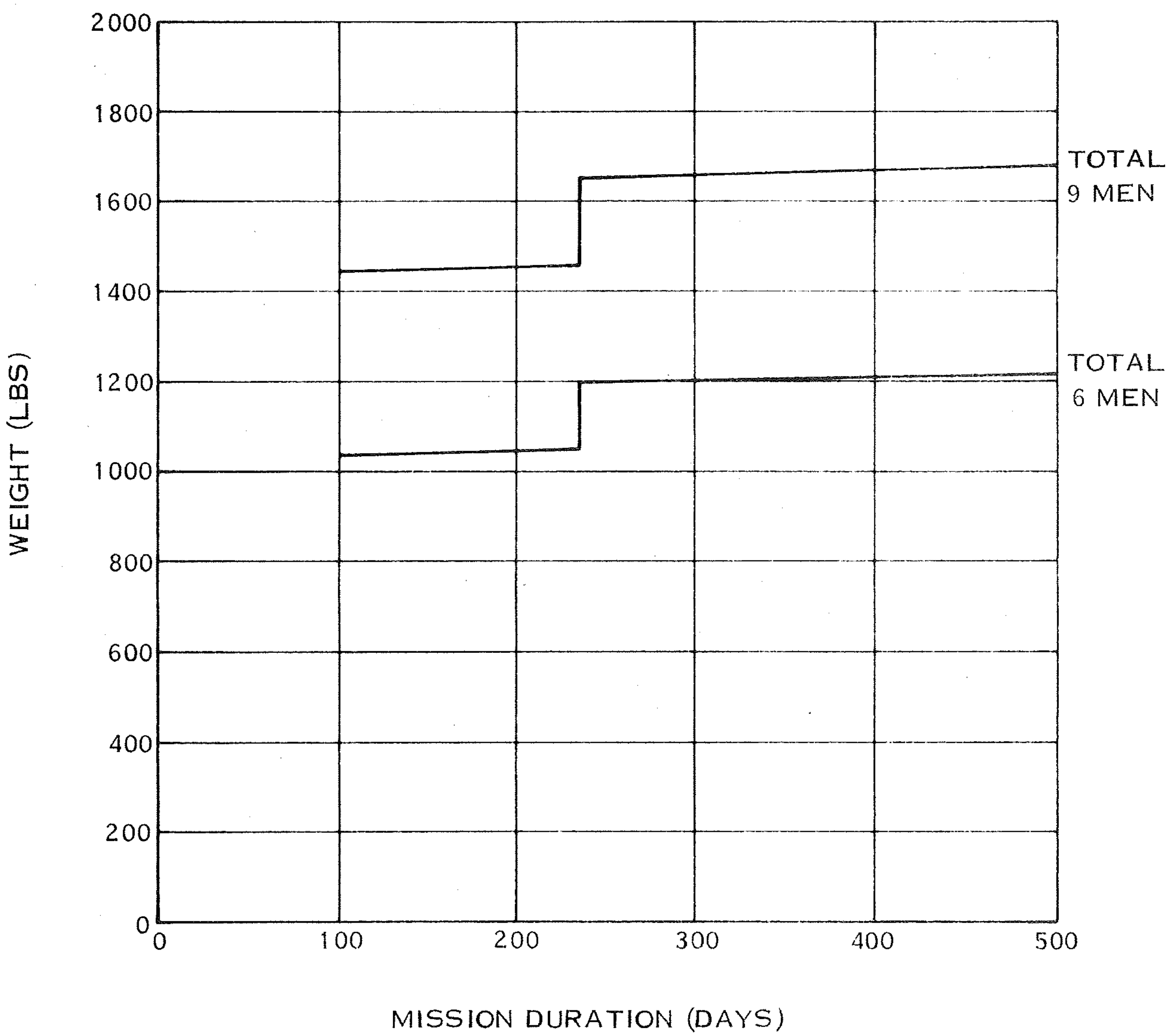

Figure 45. CO_2 Concentration - Electrodialysis.

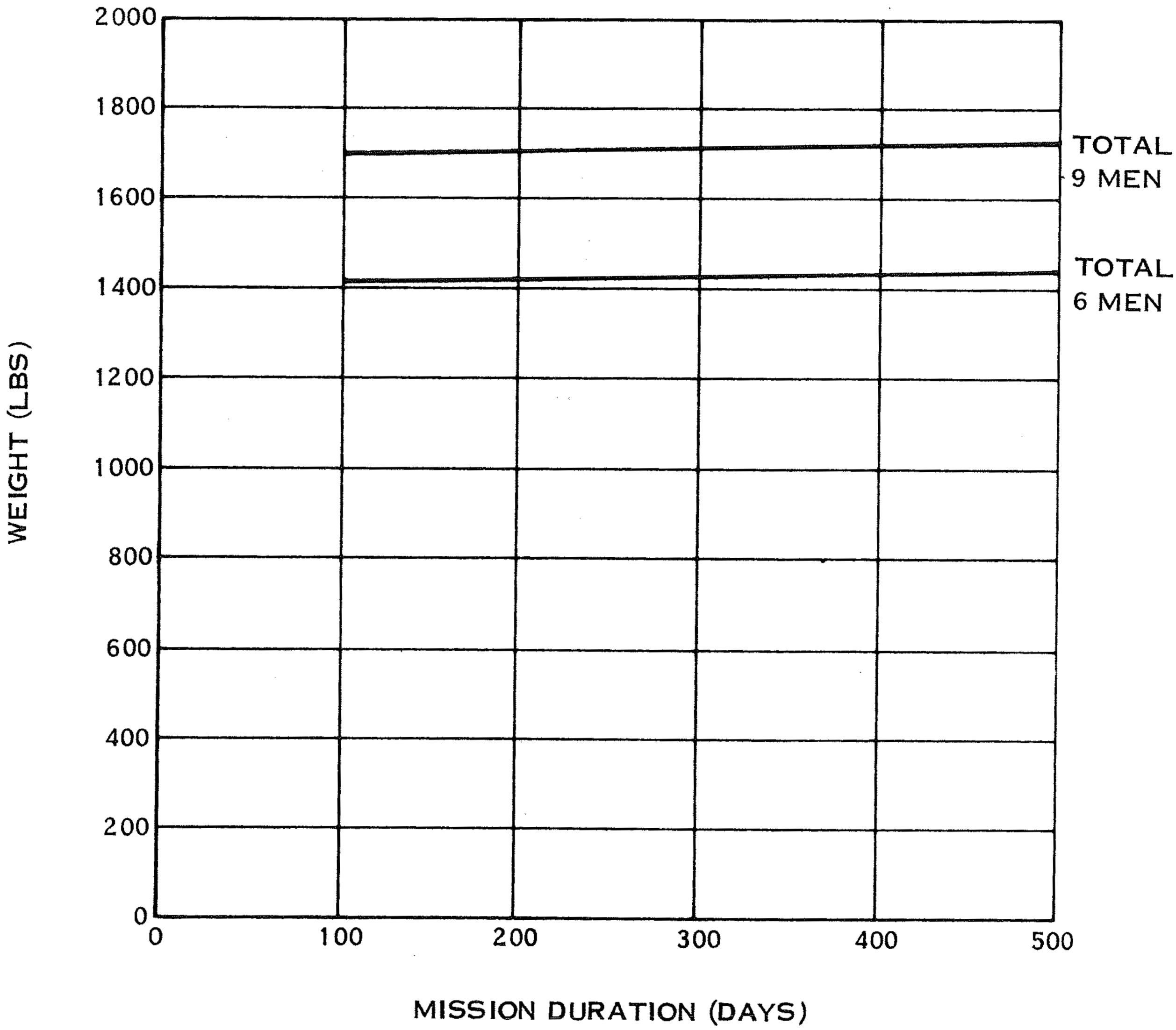

Figure 46. CO_2 Concentration - Carbonation Cell.

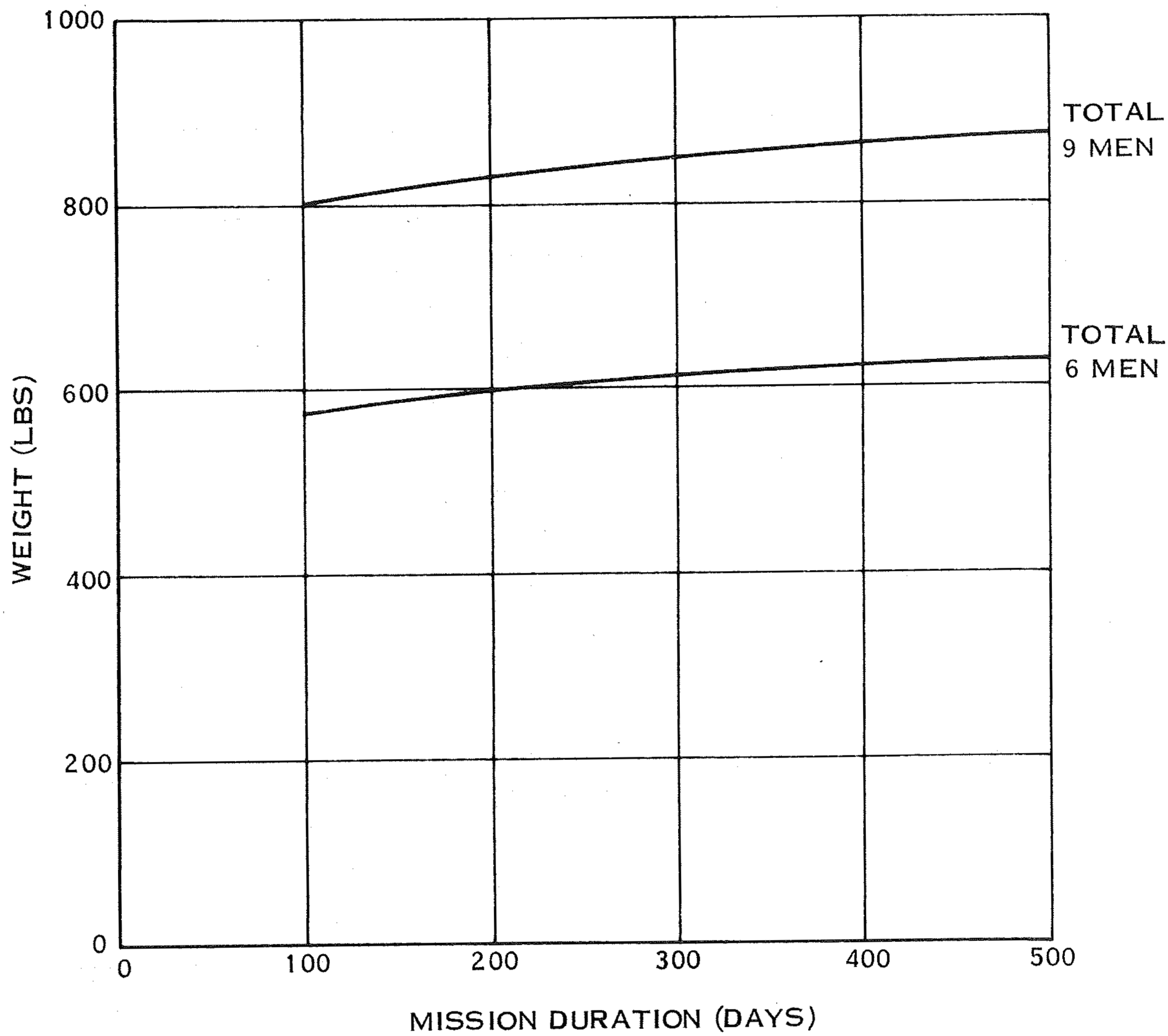

Figure 47. CO_2 Concentration - H_2 Depolarized Cell.

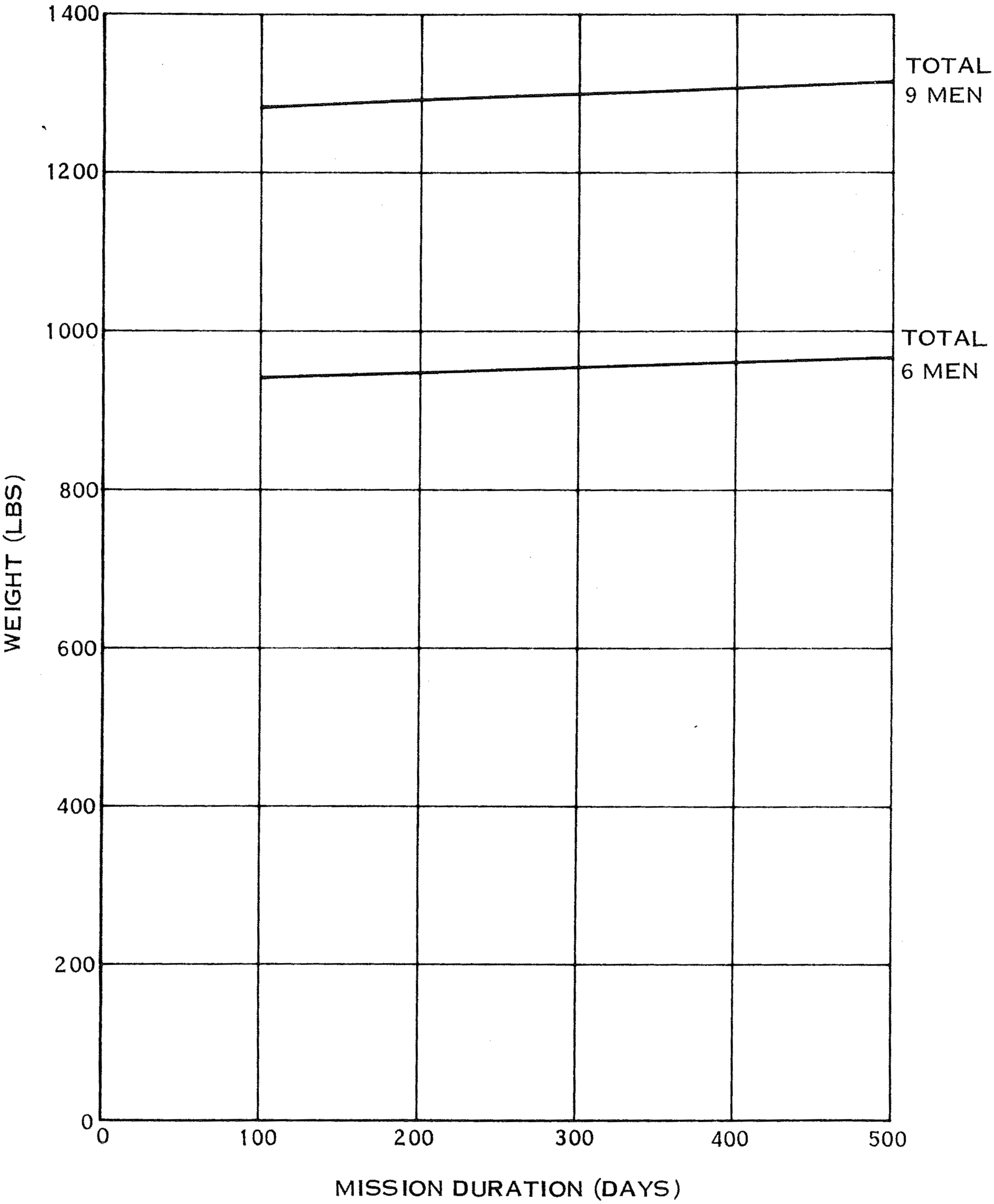

Figure 48. CO_2 Concentration - Membrane Diffusion.

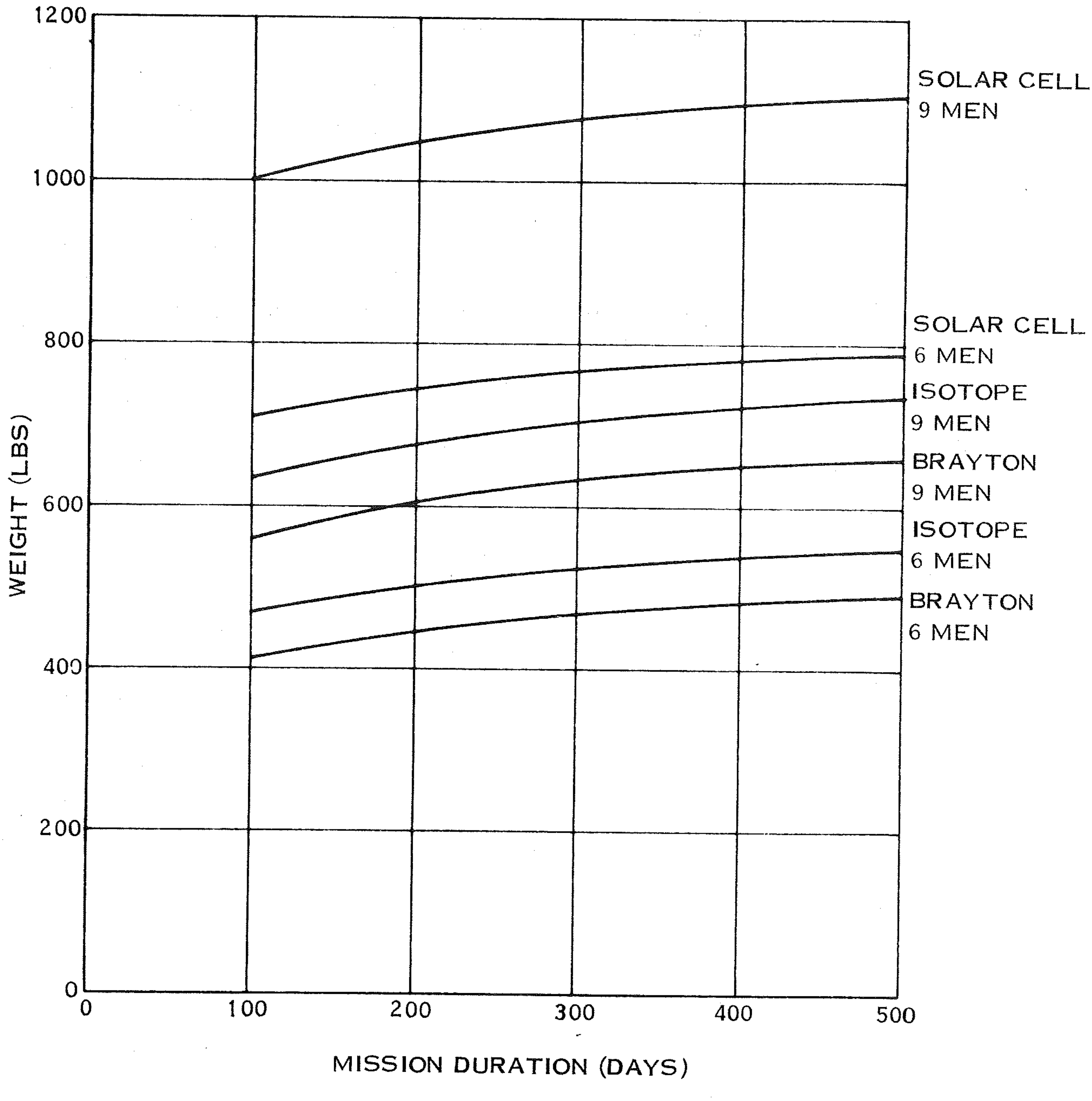

Figure 49. CO_2 Concentration - Liquid Absorption.

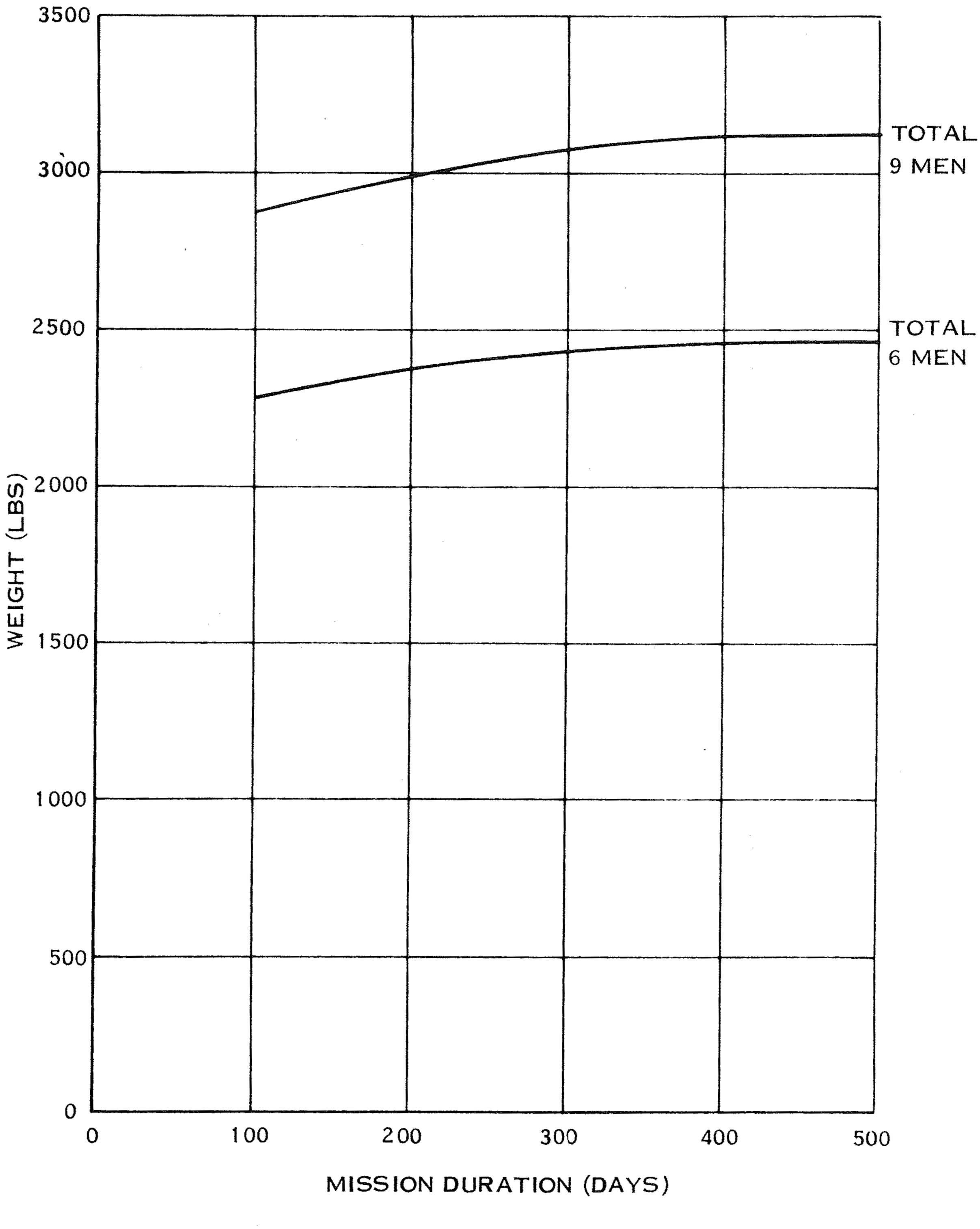

Figure 50. CO_2 Concentration - Mechanical Freezeout

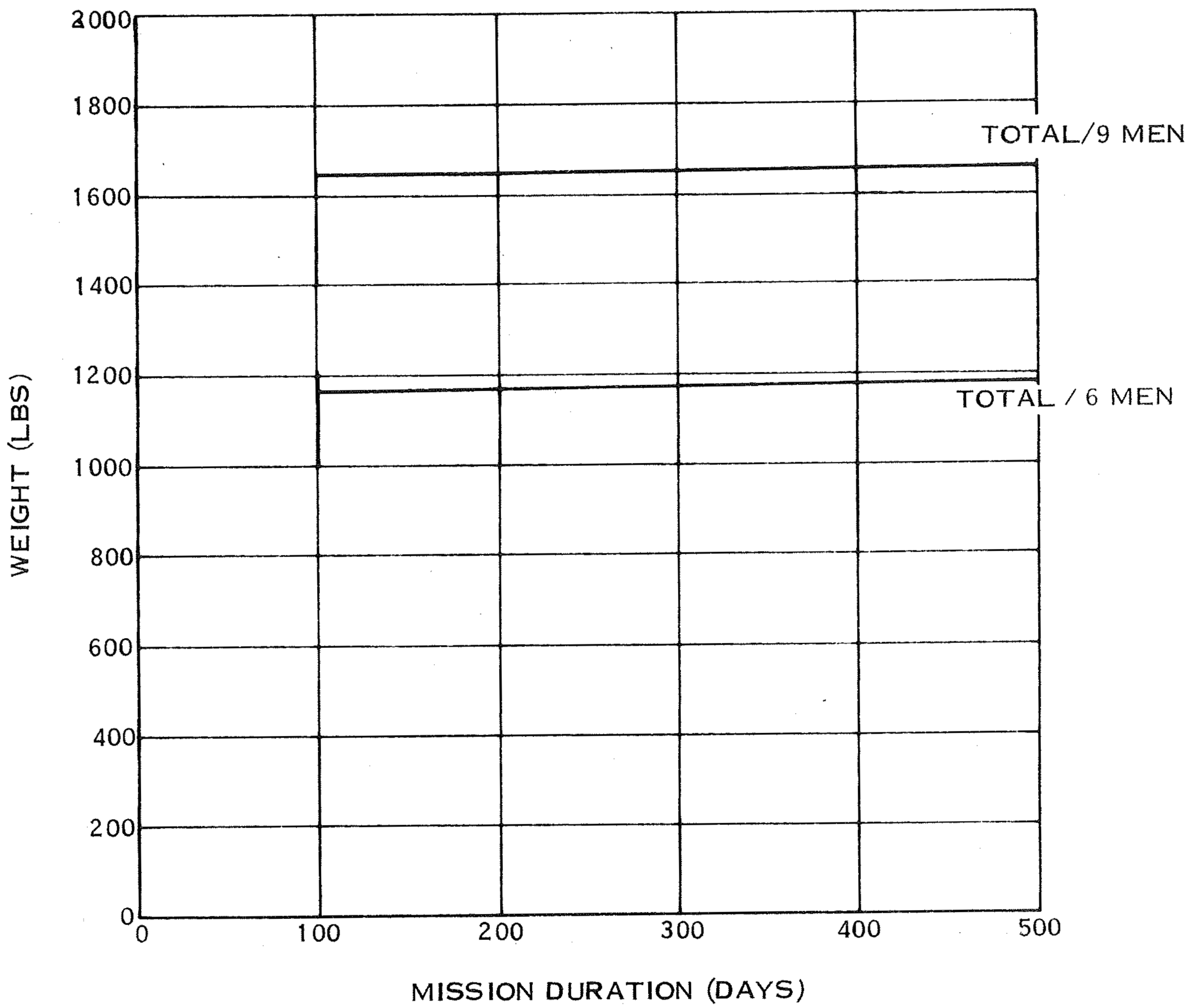

Figure 51. Electrolysis - Cabin Air.

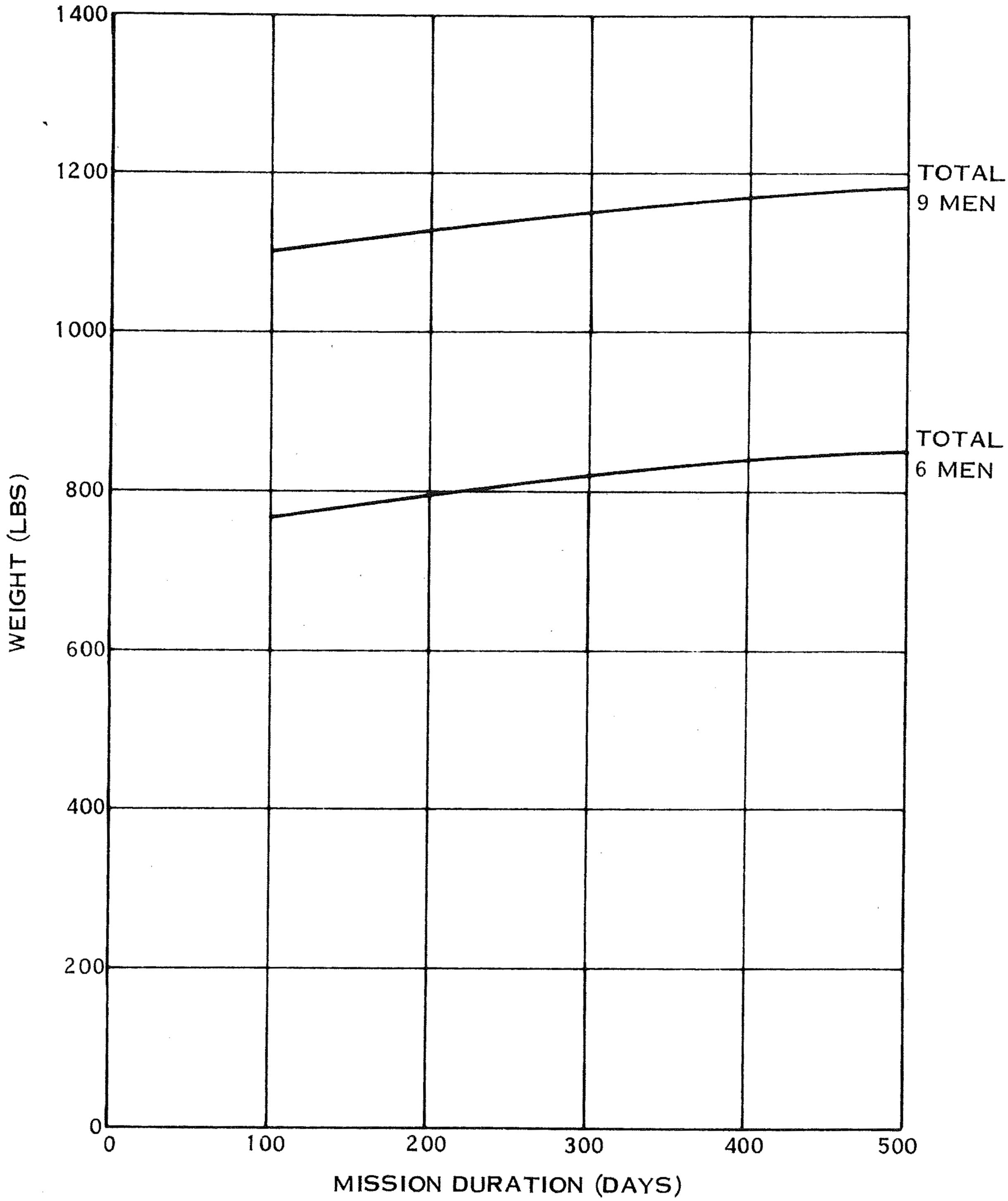

Figure 52. Electrolysis - Gas Circulation.

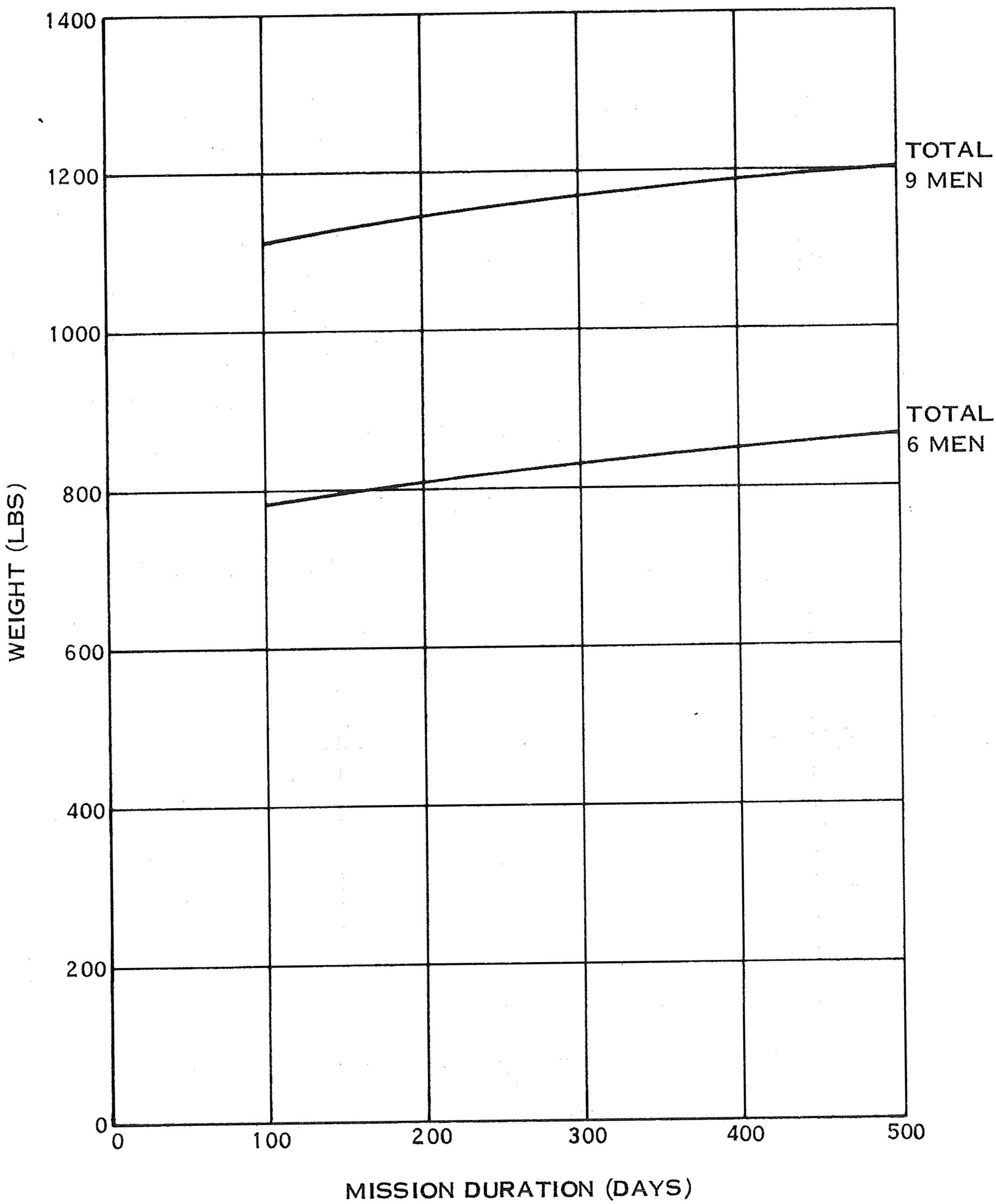

Figure 53. Electrolysis - Wick Feed.

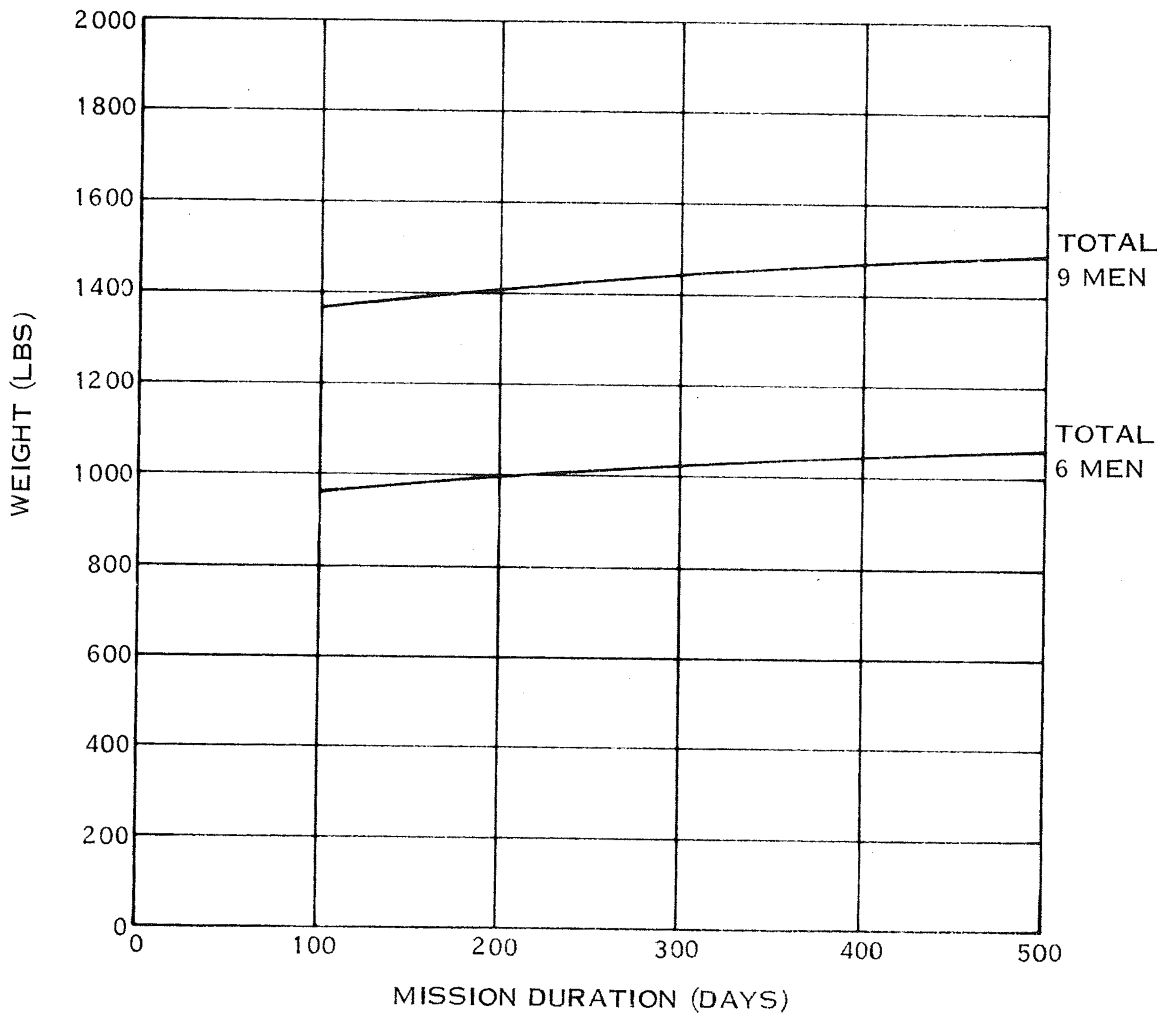

Figure 54. Electrolysis - Ion Exchange Membrane.

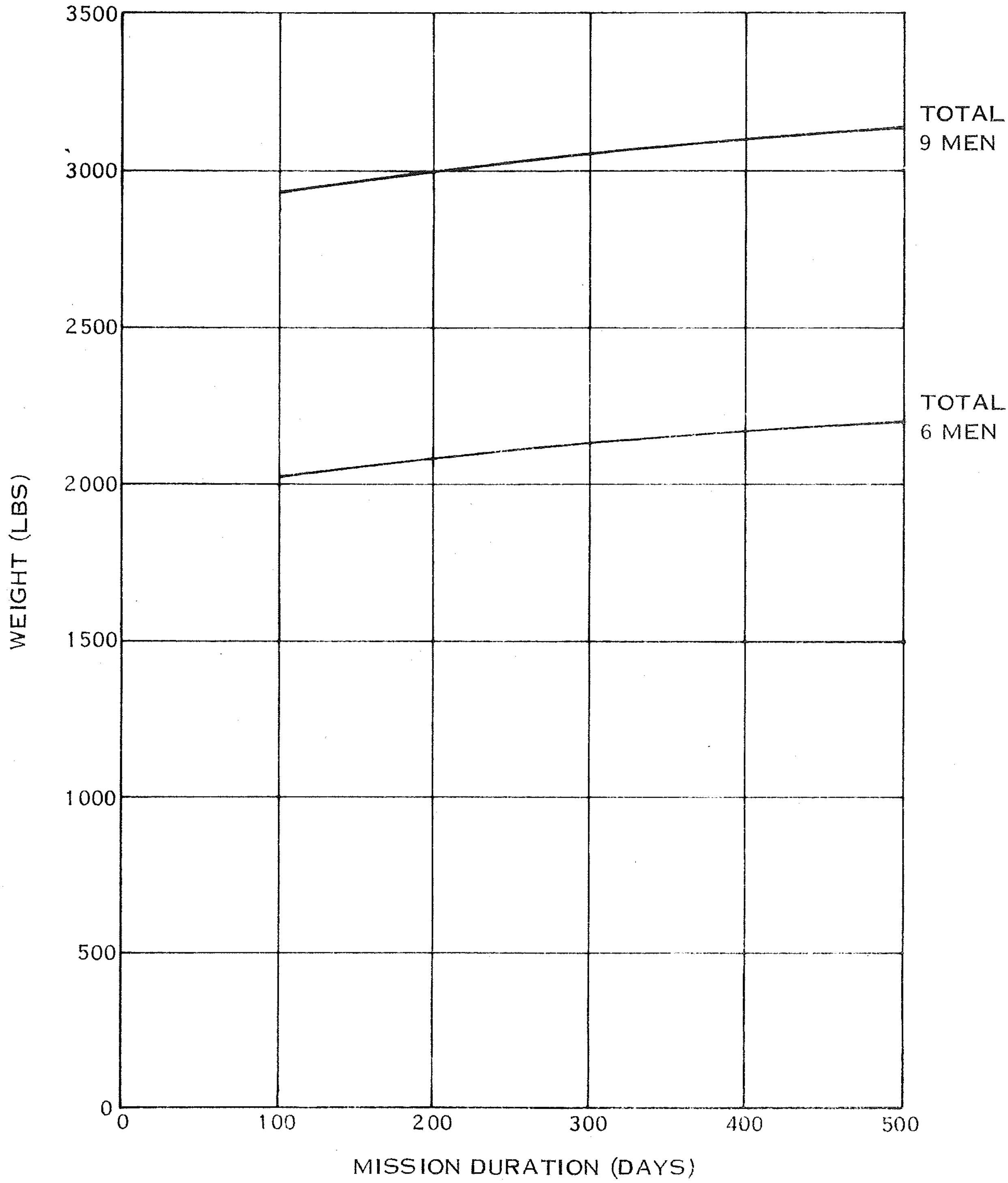

Figure 55. Electrolysis - Ion Exchange Resin

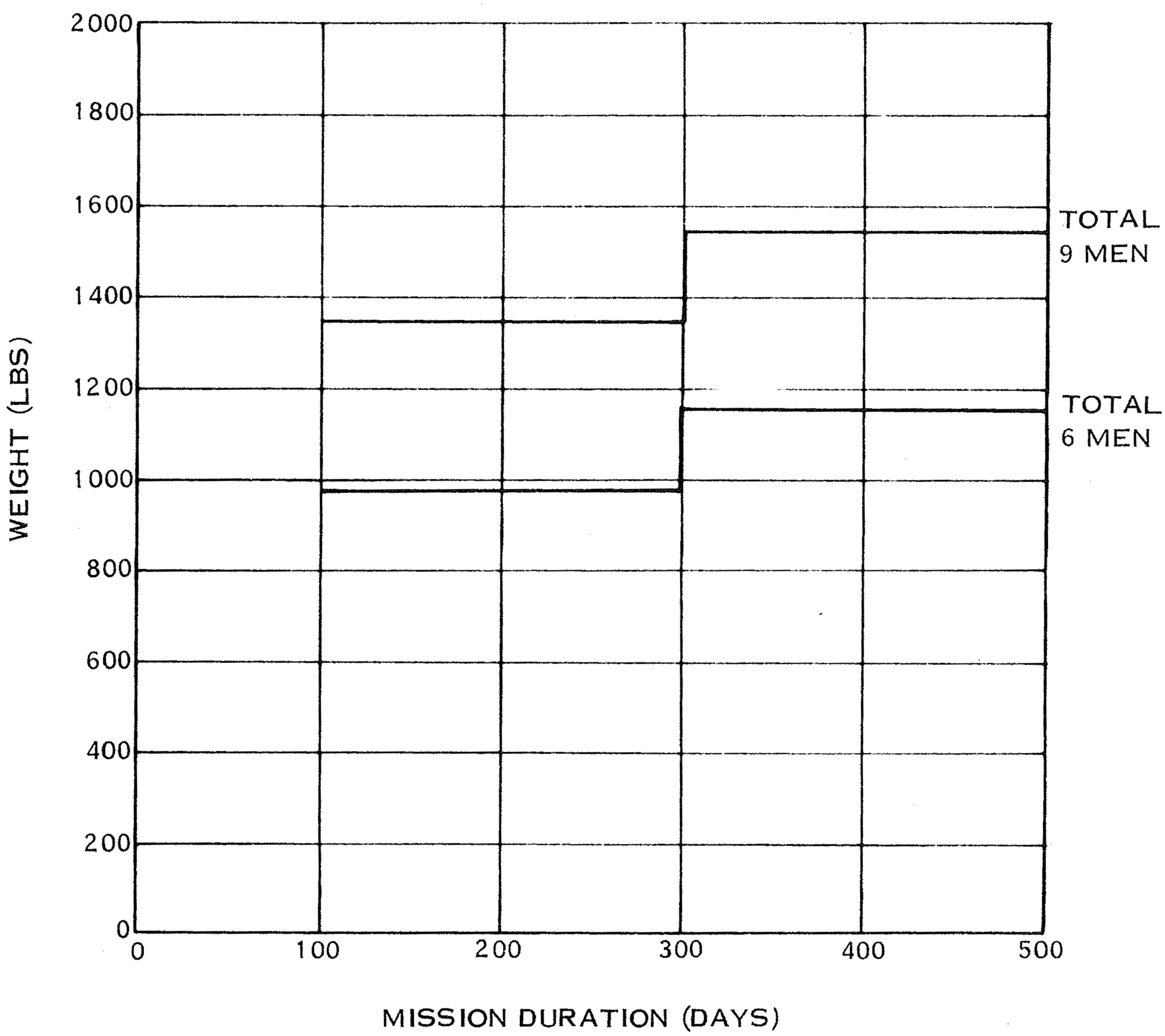

Figure 56. Electrolysis - Circulating Electrolyte.

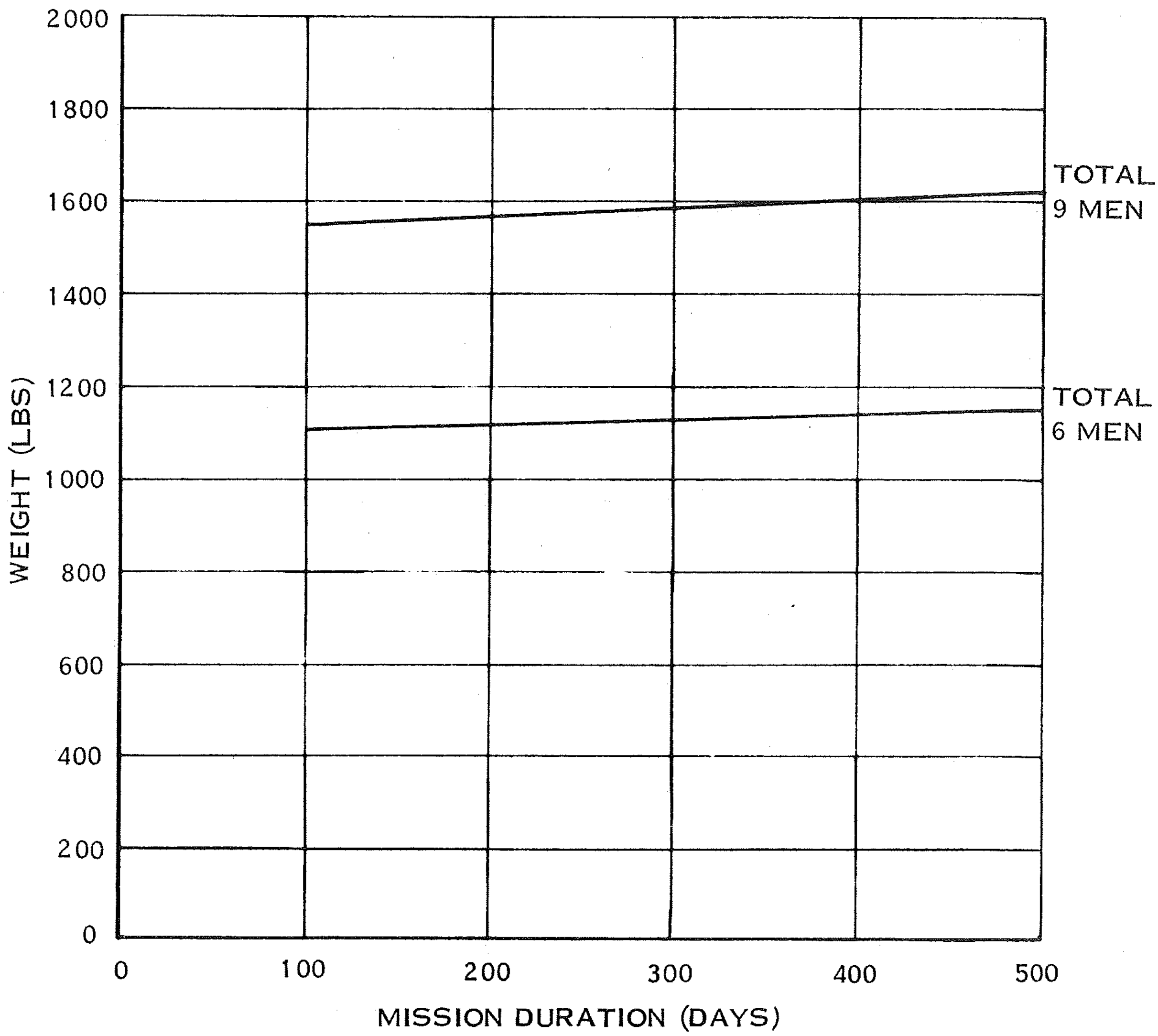

Figure 57. Electrolysis - Rotating Unit.

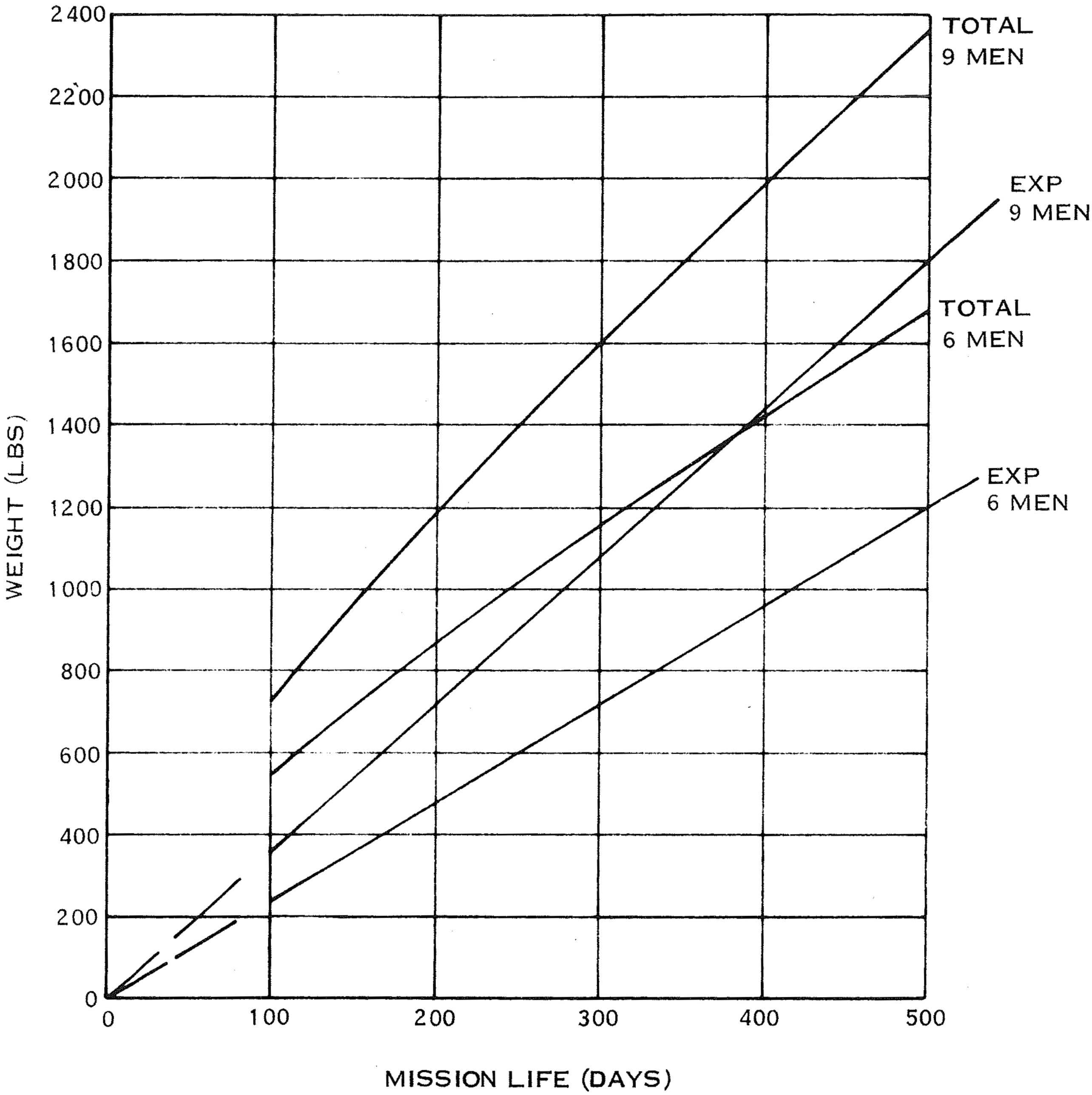

Figure 58. Waste Control - Liquid Germicide.

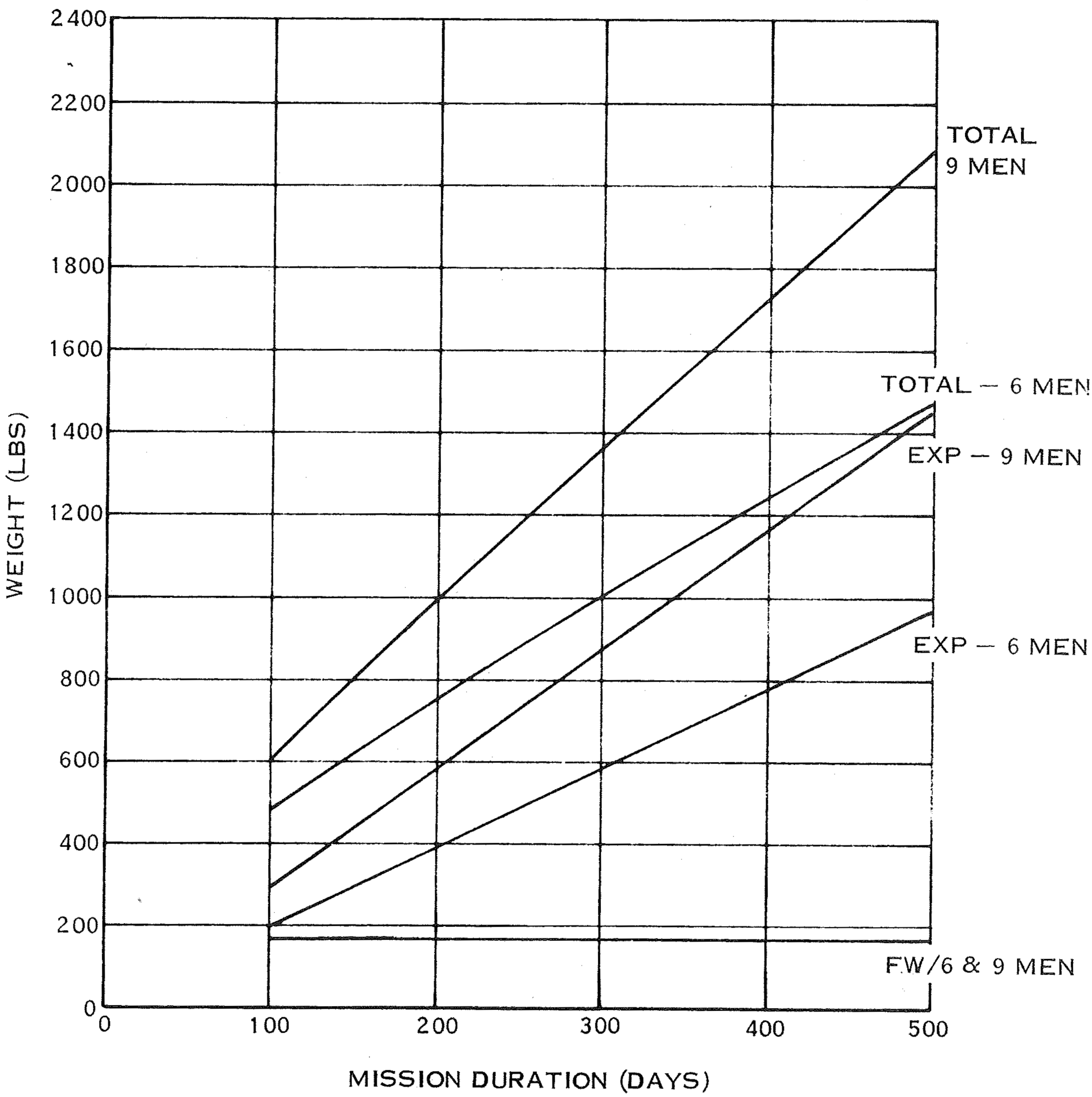

Figure 59. Waste Control - Integrated Vacuum Drying.

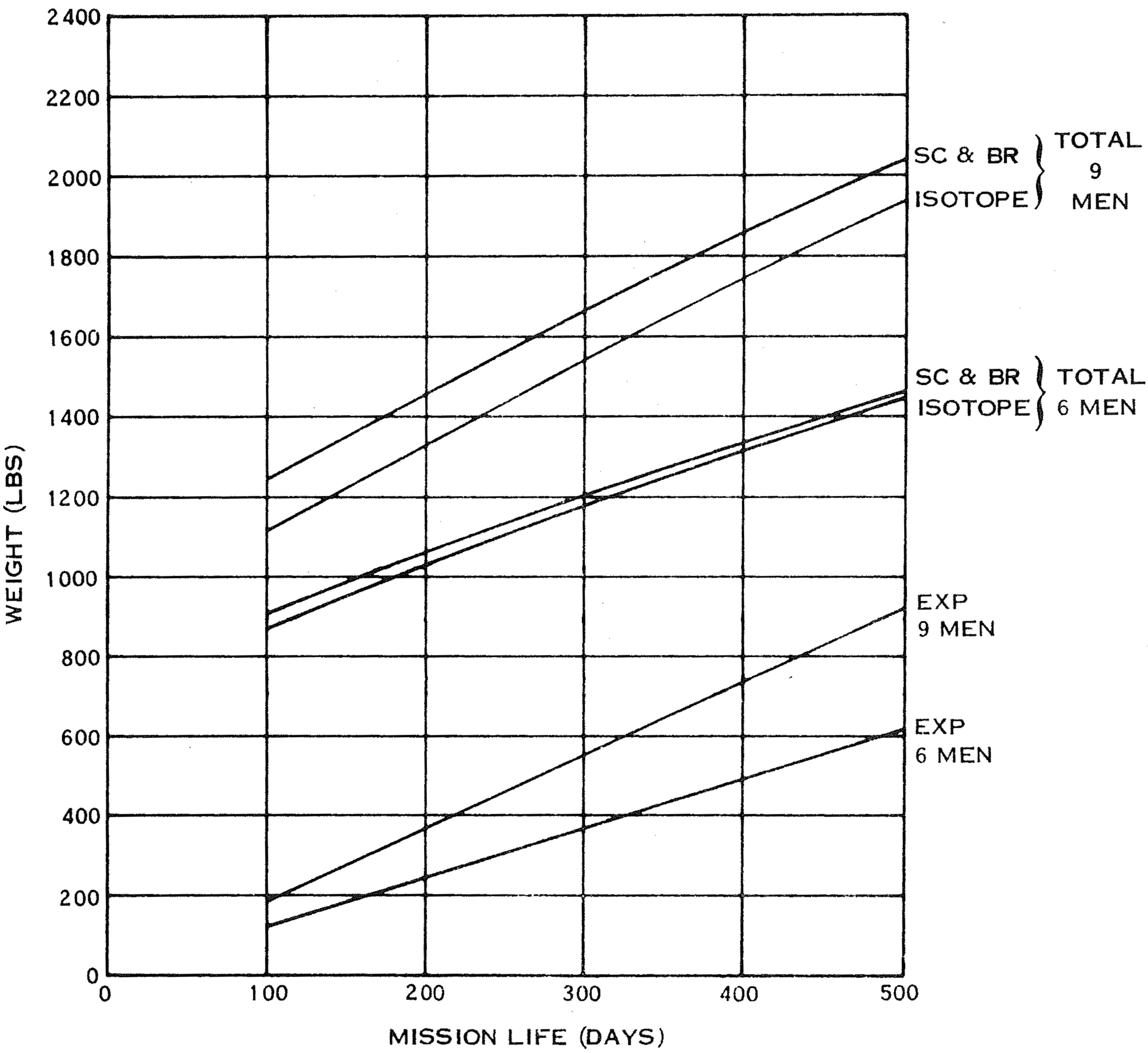

Figure 60. Waste Control - Integrated Vacuum Decomposition.

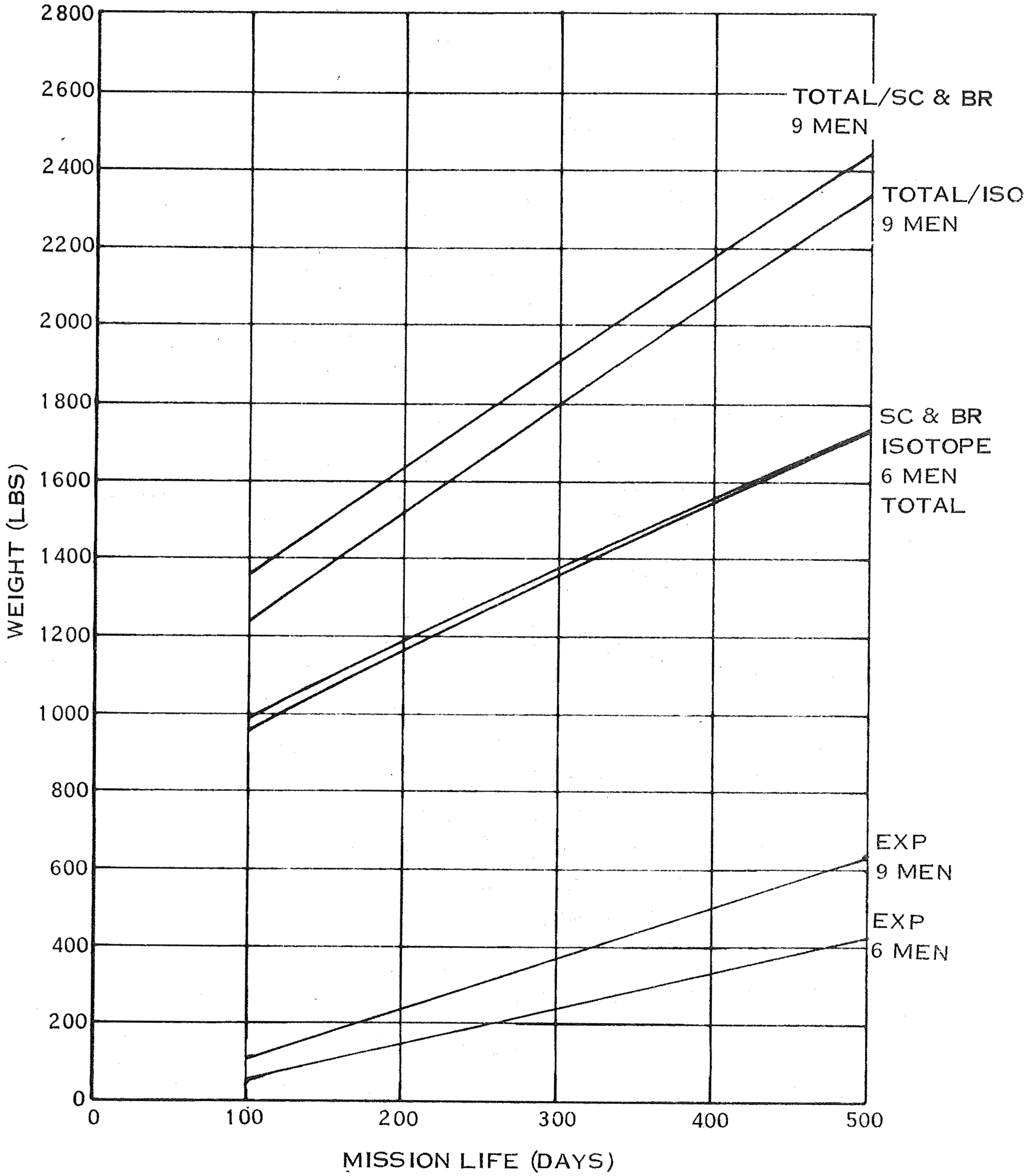

Figure 61. Waste Control - Pyrolysis/Batch Incineration.

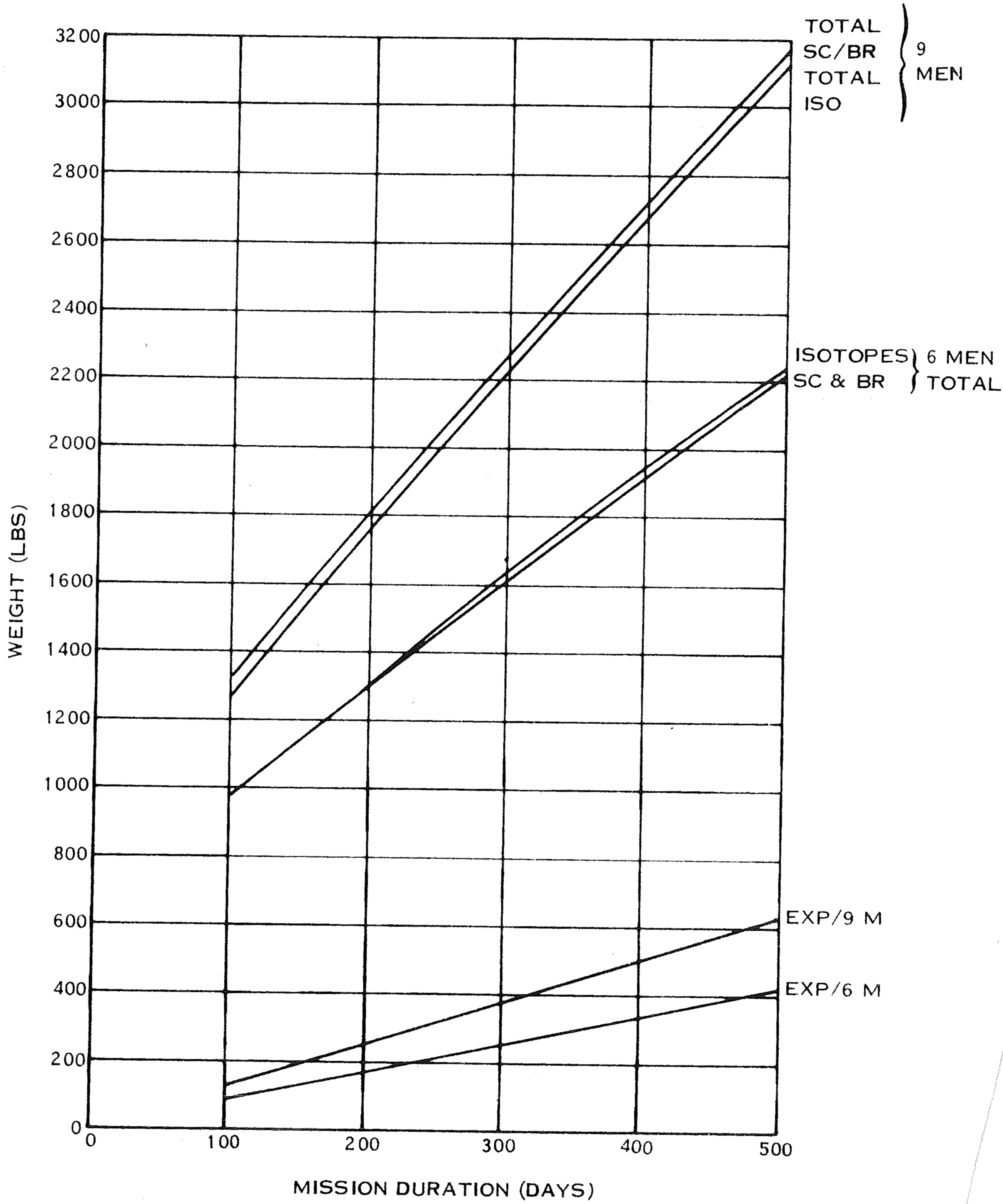

Figure 62. Waste Control - Flush Flow O_2 Incineration.

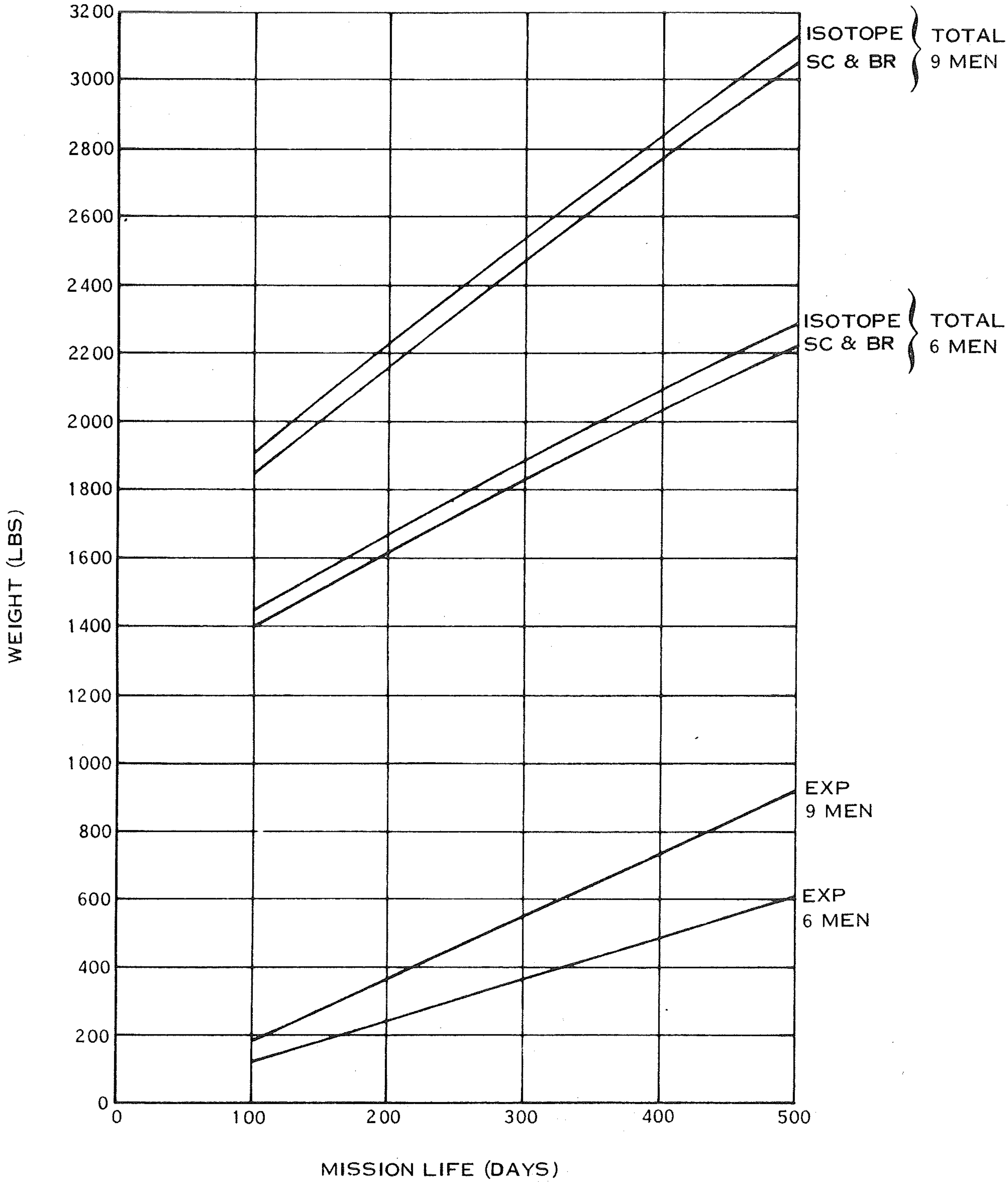

Figure 63. Waste Control - Wet Oxidation.